NUTRITIONAL EVALUATION OF FORAGE BARLEY VARIETIES FOR SILAGE

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ABSTRACT

A lack of information about nutritional and digestibility characteristics of common barley varieties grown for silage in western Canada has resulted in producers selecting varieties more on yield and other agronomic characteristics as opposed to nutritional value. The overall objective of this research was to evaluate nutritional and 30-h NDF digestibility ($NDFD_{30h}$) characteristics of common Canadian barley varieties, changes in $NDFD_{30h}$ characteristics of these varieties with advancing maturity and the effect of feeding these varieties on the performance of feedlot steers.

A nutritional evaluation of commercial barley silage samples harvested at mid-dough stage indicated that CDC Cowboy had a greater ($P < 0.01$) $NDFD_{30h}$ relative to Legacy and Xena with CDC Copeland, Falcon and AC Metcalfe intermediate. However, in a subsequent trial, growing CDC Cowboy, CDC Copeland and Xena (high, intermediate and low $NDFD_{30h}$ respectively) and harvesting on the same day across varieties did not ($P > 0.05$) result in variability in $NDFD_{30h}$. A feedlot and metabolism trial utilizing the 3 barley varieties at 2 (HIGH and LOW) levels of inclusion indicated that backgrounding steers fed CDC Cowboy and HIGH silage diets had lower ($P < 0.01$) DMI, ADG and end of backgrounding BW while steers fed HIGH silage finishing diets had compensatory gain relative to those fed LOW silage diets. Ruminal fermentation and total tract digestibility characteristics of heifers fed backgrounding and finishing diets were similar ($P > 0.05$) across treatments.

When CDC Cowboy, CDC Copeland and Xena were seeded, treated and harvested from replicated plots at four stages of maturity (milk, early-, mid- and hard-dough) over 2 crop years, there was a variety × maturity interaction with CDC Cowboy having greater ($P < 0.01$) $NDFD_{30h}$ at early-dough than Xena and greater ($P < 0.01$) $NDFD_{30h}$ at hard-dough than CDC Copeland. As

such, there is potential for producers to select barley varieties with enhanced nutritional and agronomic characteristics. Harvesting CDC cowboy at early-dough for silage for dairy and CDC Cowboy and Xena at hard-dough for swath grazing would likely improve the nutritive value of forage and could lead to specific maturity targets for different farm operations (beef vs. dairy).

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AC	Agriculture and Agri-Food Canada
ADF	Acid detergent fiber
ADG	Average daily gain
ADICP	Acid detergent insoluble crude protein
ADIN	Acid detergent insoluble nitrogen
AOAC	Association of Official Analytical Chemists
A:P	acetate:propionate ratio
bmr	brown mid-rib
BW	Body weight
Ca	calcium
CBGA	Canadian Beef Grading Agency
CCAC	Canadian Council on Animal Care
CDC	Crop Development Centre
cfu	colony forming unit
Cl	Chlorine
cm	centimeter

CNCPS	Cornell Net Carbohydrate and Protein System
CO_2	Carbon dioxide
CP	Crude protein
CPM	Cornell Penn Miner
CRD	Completely randomized design
Cu	copper
cv	cultivar
d	Day
DE	digestible energy
DM	Dry matter
DMI	Dry matter intake
DNDF	potentially digestible NDF
EBWT	end of backgrounding body weight
EDDM	effectively degradable dry matter
EDNDF	effectively degradable NDF
EE	ether extract
eg.	example

ESC	ethanol soluble carbohydrate
FA	ferulic acid
Fe	iron
G:F	kg gain:kg feed
h	hour
ha	hectare
HCW	Hot carcass weight
INDF	Indigestible NDF
$INDF_{288h}$	INDF measured by 288 h ruminal incubation
K	potassium
kg	kilogram
L	level of inclusion in the diet
LAB	lactic acid bacteria
LSD	Latin square design
mE	milliequivalent
Mg	magnesium
mL	milliliters
Mn	manganese
N	nitrogen
Na	sodium

NDF	Neutral detergent fiber
NDFD	Neutral detergent fiber digestibility
$NDFD_{6h}$	NDFD measured after 6 h *in vitro* $Daisy^{II}$ incubation
$NDFD_{30h}$	NDFD measured after 30 h *in vitro* $Daisy^{II}$ incubation
NDICP	neutral detergent insoluble crude protein
NE_m	Net energy maintenance
NE_g	Net energy gain
NFC	non-fiber carbohydrate
NH_3-N	ammonia nitrogen
NPN	nonprotein nitrogen
NRC	nutrient requirement of cattle
NSC	non-structural carbohydrate
OM	organic matter
P	Probability
P	Phosphorus
peNDF	physically effective NDF
RCBD	Randomized complete block design
RDP	rumen degradable protein
r^2	coefficient of determination
S	sulphur
SARA	Subacute ruminal acidosis

SAS	Statistical analysis system
SD	Standard deviation
SEM	standard error of pooled mean
SP	soluble protein
t	tonne
TCL	theoretical chop length
TDN	total digestible nutrients
V	variety of barley
V × L	Variety × Level of inclusion interaction
V × M	Variety × Maturity at harvest interaction
VFA	Volatile fatty acid
WSC	water soluble carbohydrate
wt	Weight
YG	yield grade
Zn	zinc
%	Percentage

1.0 General Introduction

Feedlot and dairy operations in western Canada rely primarily on whole crop barley (*Hordeum vulgare* L.) as the principal forage source (McAllister et al. 1995) due to the short growing season of the northern prairies (Juskiw et al. 2000) and the favorable nutritional and ensiling characteristics of barley (Kaulbars and King 2004). Barley is well adapted to the diverse growing conditions of western Canada and has superior forage quality among small grain cereal forages (Baron et al. 2000; Kaulbars and King 2004). Barley varieties commonly grown for silage are either 2- or 6 row, standard or semi-dwarf, feed or malting type, or have rough or smooth awns. Baron et al. (2000) reported that there is variability among barley varieties for forage quality. However, detailed nutrient and digestibility characteristics of barley varieties grown for silage in western Canada is lacking. Thus, in deciding which variety to grow for silage, producers tend to place more emphasis on yield and other agronomic characteristics rather than on nutritional value.

The NDF content of barley silage typically ranges from less than 40% (Addah et al. 2012) to over 60% (Dairy one forage lab., Ithaca, NY) depending on stage of maturity at harvest. The NDF digestibility (NDFD) has a significant influence on the available-energy content of forages. Studies with high NDFD corn varieties (i.e. brown mid-rib; bmr) have shown improved dry matter intake (DMI; Rook et al., 1977; Oba and Allen 1999b; Barrière et al., 2004) and milk yield (Oba and Allen 1999b; Ballard et al., 2001; Ebling and Kung 2004) in dairy cattle. These improvements in dairy cow performance were attributed to reduced ruminal fill, increased ruminal turnover of NDF and potential improvement in dietary energy status in cows fed high NDFD forage (Mertens 1987; Oba and Allen 1999b; Oba and Allen 2000). Oba and Allen (2011) reported that 30 h *in vitro* NDF digestibility values best describe the normal retention time of

forage NDF in the rumen. In a recent evaluation of barley silage varieties varying in 30 h NDFD ($NDFD_{30h}$), Oba and Swift (2014) reported improved feed efficiency (kg milk per kg DMI) in dairy cattle fed a barley silage variety with a higher $NDFD_{30h}$ (cv. Falcon) relative to one with a lower $NDFD_{30h}$ (cv. Tyto). These authors reported that greater $NDFD_{30h}$ of barley silage was associated with an increased energy supply to dairy cows without an increase in DMI. Moreover, Chow et al. (2008) reported increased BW gain for dairy cattle fed high $NDFD_{30h}$ barley silage. It was concluded that high $NDFD_{30h}$ of barley silage resulted in increased availability of dietary energy that was partitioned to BW gain. However, effect of $NDFD_{30h}$ of common barley varieties grown for silage in western Canada on the growth performance of feedlot steers has not been evaluated.

Barley forages with high $NDFD_{30h}$ potentially allow for increased inclusion of forage at equal energy density allowing for a reduction in metabolic disorders and possibly feed costs. Finishing feedlot steers are at risk of developing ruminal acidosis owing to greater content of grain in the diet. An increase in level of inclusion of barley silage in feedlot diets especially during finishing can be beneficial in reducing the risk of ruminal acidosis (Koenig and Beauchemin 2011). Barley varieties grown for forage with higher NDFD potentially allows for a greater inclusion of forage in backgrounding and finishing diets without compromising the production potential of high producing animals (Oba 2013). Greater NDFD is also correlated to greater TDN content and availability of dietary energy (Hoffman and Combes 2004).

Barley is generally harvested in western Canada for silage at the mid-dough stage of maturity (Baron et al. 1992) balancing DM yield and nutrient quality. Rosser et al. (2013) reported that the effective degradable DM (EDDM) yield of barley (cv. CDC Cowboy) for swath grazing increased with advancing maturity from head elongation through to full maturity.

However, the effect of maturity at harvest of barley varieties for forage production on $NDFD_{30h}$ has not been evaluated. As reported by Baron et al. (2000), inherent variability in nutrient composition among barley varieties could lead to potential differences in the stage of maturity at which specific varieties should be harvested for optimum nutritional value. Further, detailed evaluation of nutrient and digestibility characteristics of barley varieties at different stages of maturity may lead to insights into a variety specific stage of maturity for harvest that suits the type of farm operation, specifically beef vs dairy producers. This study will provide information on variability among common barley varieties grown for silage in western Canada in terms of nutrient composition and $NDFD_{30h}$ and the effect of feeding barley silage varieties that vary in $NDFD_{30h}$ on the growth performance, carcass characteristics, ruminal and total tract digestibility and ruminal passage rate in feedlot cattle.

The intent of the following literature review is to provide background on growing barley varieties for silage, chemical and nutrient characteristics of forage barley, barley silage fermentation, factors affecting barley silage quality, and performance of beef and dairy cattle fed barley silage.

2.0 Literature Review

2.1 Introduction

Feedlot and dairy operations in western Canada primarily rely on whole-crop barley (*Hordeum vulgare* L.) silage as the principal forage source because of its nutritional and ensiling characteristics (Kaulbars and King 2004). These authors reported that barley silage has greater CP content and DM digestibility resulting in greater DM intake and milk yield in dairy cattle among the small grain cereal silages evaluated. McCartney and Vaage (1994) reported that whole crop barley harvested at mid-dough stage for silage resulted in greater dry matter intake (DMI) and average daily gain (ADG) in growing beef cattle relative to those fed oat or triticale silage. Similarly, Addah et al. (2011) reported greater end of trial body weight (BW), ADG and feed conversion efficiency for beef steers fed barley silage relative to those fed corn silage based backgrounding diets.

Barley silage is characterized by a high cell wall content ranging from less than 40 to over 60% neutral detergent fiber (NDF) (Addah et al. 2012a; Dairy one forage lab, Ithaca, NY) depending up on stage of maturity at harvest. Ruminal and total tract digestibility of NDF (NDFD) is lower than that of non-structural carbohydrates such as starch (Huhtanen et al. 2006). The NDF fraction is comprised of cellulose, hemicellulose and lignin. Digestibility of these cell wall components influences dry matter intake and energy availability to the animal (Oba and Allen 1999b; Hoffman and Combs 2004). Studies with high NDFD corn varieties (i.e. brown mid-rib; bmr) have shown improved dry matter intake (DMI; Rook et al. 1977; Oba and Allen 1999b; Barrière et al. 2004) and milk yield (Oba and Allen 1999b; Ballard et al. 2001; Ebling and Kung 2004) in dairy cattle. These improvements in dairy cow performance were

attributed to reduced ruminal fill, increased ruminal turnover of NDF and potential improvement in dietary energy status in cattle fed high NDFD forage (Mertens 1987; Oba and Allen 1999b; Oba and Allen 2000). Moreover, Oba and Swift (2014) reported improved feed efficiency (kg milk per kg DMI) in dairy cattle fed a barley silage variety with a higher 30 h NDFD ($NDFD_{30h}$; cv. Falcon) relative to one with a lower $NDFD_{30h}$ (cv. Tyto). With respect to beef cattle, there has been very little research that has examined the $NDFD_{30h}$ characteristics of barley silage and the potential differences that may exist between varieties.

2.2 Silage Fermentation and Factors Affecting Silage Fermentation

2.2.1 Silage Fermentation

Silage is produced by the controlled fermentation of high moisture crops (McDonald et al. 1991). Proper ensiling effectively preserves the nutrient content of forages (Kalubars and King 2004). The quality of silage depends on the quality of forage ensiled, harvesting and ensiling techniques. Fermentation and preservation of ensiled forage is brought about by the epiphytic lactic acid bacteria (LAB) that utilize the water soluble carbohydrate (WSC) content of the forage to produce lactic acid under anaerobic conditions. The process of silage fermentation can be divided into four major phases based on the nature of biochemical processes occurring and the microorganisms involved at each stage.

2.2.1.1 Phase 1: The Aerobic Phase

Plant and epiphytic microbial respiration during harvest, chopping, filling and packing results in nutrient losses during the initial phase of ensiling when oxygen is still present (Barnhart 2008). This is unavoidable as continued plant respiration utilizes oxygen within the silo, ultimately this oxygen is used up creating an anaerobic environment for the ensiling process to continue (Muck

1988). Utilization of sugars during this phase results in DM and energy losses. Moreover, heat produced from respiration increases the temperature of the silo. A rise in silo temperature activates other enzymes such as proteases that convert plant protein nitrogen into non-protein nitrogen. Moreover, high silo temperatures increase the formation of Maillard reaction products (i.e. heat damaged protein; Muck 1988) resulting in further nutrient losses and reduction in digestibility of silage. It is desirable to have the aerobic phase as short as possible to reduce the DM and nutrient losses. Under typically ensiling conditions, phase 1 lasts for 1 - 3 d. Rapid silo filling, adequate compaction and covering of the silo significantly reduces the duration of this phase. Once oxygen in the silo is depleted, facultative bacteria predominate and the fermentation process produces organic acids, ethanol and CO_2 resulting in a decline in pH. Once the pH of silo reaches 5.0, acid tolerant lactic acid bacterial activity increases, further reducing the silage pH if buffering forces are overcome.

2.2.1.2 Phase 2: The Active Fermentation Phase

This phase is characterized by the active multiplication of obligate homofermentative LAB and rapid decline in silage pH (McAllister and Hristov 2000). The pH drop (3.8 - 4.5) is brought about by the production of lactic acid which not only helps to preserve the forage nutrients, but also facilitates release of soluble sugars from complex carbohydrates by acid hydrolysis (Addah et al. 2013). In well preserved silages, lactic acid concentration exceeds 60% of the total volatile fatty acids (VFA) produced (Seglar 2003). This phase lasts for 10 - 21 d (Seglar 2003) depending on the stage of maturity at harvest and DM content of the ensiled forage, buffering capacity, population of epiphytic microflora and ensiling conditions.

2.2.1.3 Phase 3: The Stable Phase

During this stage, no significant biochemical changes occur in silage as long as anaerobic conditions are maintained. Silage pH at this stage depends on the type of forage ensiled and the addition of inoculants. Legumes and grasses result in a relatively higher silage pH than cereals due to lower WSC and higher buffering capacity. Heterolactic bacterial inoculants generally result in a comparatively higher silage pH than homolactic inoculants (Driehuis 2001). Moreover, *Lactobacillus buchneri* in heterolactic silage inoculants can convert lactic acid produced during phase 2 of ensiling to acetic acid (Driehuis et al. 1999). This stage lasts as long as the anaerobic nature of the silo is maintained and until the silo is opened for feed out.

2.2.1.4 Phase 4: The Feed-Out Phase

During the feed-out phase, the silo is opened for feeding, exposing the silage to air promoting decomposition by spoilage organisms. Aerobic deterioration of silage is brought about by yeasts, molds and bacteria metabolizing WSC and lactate to CO_2, water and ethanol (McDonald et al. 1991). As the feed-out stage constitutes a significant phase for silage losses (McAllister and Hristov 2000), good silo management practices can reduce DM losses during this phase. Managing the silo so that 10 - 15 cm of silage is removed from the silo face on a daily basis prevents excessive exposure oxygen and thereby reduces aerobic deterioration (McAllister and Hristov 2000).

2.2.2 Factors Affecting Silage Fermentation

Primary factors affecting silage fermentation include dry matter (DM) content and chemical composition of the forage including water soluble carbohydrate (WSC) content, buffering capacity and the epiphytic microbial population present at the time of harvest.

2.2.2.1 Dry Matter Content of Barley

The DM content of barley silage is influenced by the stage of maturity at harvest and environmental growing conditions. The DM content of barley increases with advancing plant maturity (Baron et al. 1992; Khorasani et al. 1997; Borowiec et al. 1998). Rosser et al. (2013) reported an increase in DM content from 14.2% for whole crop barley (cv. CDC Cowboy) harvested at head elongation to 41.9% for that harvested at hard-dough. Recommended DM content of barley for ensiling is 30 - 40% which corresponds to mid-dough (Baron et al. 1992; Kaulbars and King 2004). Daynard (1978) reported nutritive losses due to seepage when the DM of ensiled small grain cereals was below 30%, while DM above 40% may result in insufficient compaction and exclusion of air during ensiling (Baron et al. 1992; Juskiw et al. 2000; Kaulbars and Kang 2004). Similarly, Hargreaves et al. (2009) reported restricted fermentation of barley when DM exceeded 40% at the time of ensiling due to lower water soluble carbohydrate (WSC) content.

2.2.2.2 Water Soluble Carbohydrate Content of Barley

Water soluble carbohydrates are the major source of energy for lactic acid bacteria during silage fermentation and consist of simple sugars (glucose, fructose and sucrose) and fructosans. Other plant carbohydrates like starch, cellulose and hemicellulose are used only to a limited extent during fermentation (Kaulbars and King 2004). Hargreaves et al. (2009) reported a decrease in WSC content as the maturity of fresh barley forage increased from milk to hard-dough. Concentrations of 6 - 12% (% DM) WSC in forages is considered to be ideal for proper ensiling (Kaulbars and King 2004). At mid-dough, barley forage contains high levels (10 - 20% DM) of WSC (McAllister et al. 1995; Hargreaves et al. 2009). However, good quality silage can still be

produced from forages (eg. corn) having lower WSC concentrations and lower buffering capacity (Addah et al. 2011).

2.2.2.3 Epiphytic Microbial Population of Barley

Epiphytic microbes of barley represent the microorganisms associated with barley forage prior to ensiling (McAllister and Hristov 2000) which include lactic acid bacteria, acetic acid bacteria, enterobacteria, Clostridia, Bacillus spp. yeast and molds (McDonald et al. 1991). Number, type and activity of epiphytic microbes present at the time of ensiling affects the fermentation process. Spoelstra (1991) reported that forges should contain at least 10^6 colony forming units (cfu) per gram of LAB for successful fermentation. Aerobic epiphytic microbial activity is inhibited during ensiling by anaerobiosis or acidification (Pahlow 1991). Anaerobic epiphytic bacteria such as Clostridia results in silage deterioration and spoilage (McDonald et al. 1991). Presence of homolactic as opposed to heterolactic LAB in the epiphytic population enhances the decline in silage pH (McAllister and Hristov 2000). However, heterolactic LAB can improve the aerobic stability of silage during feed out.

2.2.2.4 Buffering Capacity of Barley

Buffering capacity is a measure of the degree to which the forage sample resists a change in pH (Kaulbars and King 2004; Kung 2010). It is defined as the milliequivalents (mE) of alkali required to change the pH of 1 kg of DM from 4 to 6 (McDonald et al. 1991). Organic acids (malic, succinic and glyceric acid) and salts, plant proteins, orthophosphates, sulphates, nitrates and chlorides in plants are responsible for the buffering capacity of forage. Forages with high buffering capacity require more lactic acid to lower the silage pH than forage with low buffering capacity (Kung 2010). McAllister and Hristov (2000) reported a buffering capacity of 220 mE

kg^{-1} DM for green feed barley at early-dough relative to 104 mE kg^{-1} DM at late-dough. Similarly, Borowiec et al. (1998) reported a decrease in buffering capacity for whole crop barley with advancing maturity. These authors reported a higher buffering capacity (244 mE kg^{-1} DM) for barley harvested at head emergence relative to that harvested at milk (179 mE kg^{-1} DM) or soft-dough (145 mE kg^{-1} DM)

2.2.2.5 Silage Additives

Silage additives are used to reduce DM losses, preserve nutrients and reduce spoilage during feed out (Kaulbars and King 2004). However, it should be noted that good quality silage can be made without the addition of silage additives (Addah et al. 2011) provided good agronomic and ensiling practices are followed. Choice of additive depends on the effectiveness, appropriateness to the crop type and the ease of application (Elferink et al. 2000). Major types of silage additives include fermentation inhibitors, fermentation stimulants, nutrients, aerobic deterioration inhibitors and absorbents. Silage microbial inoculants are used to enhance post-ensiling decline in pH and for DM and nutrient retention (Kung and Ranjit 2001). However, silage pH of whole crop cereals including barley generally approaches or drops below 4 even without silage additives (McAllister and Hristov 2000).

2.3 Forage Crops for Silage in Western Canada

Barley, oat, triticale and wheat are the most common cereal crops grown for silage in western Canada (Kaulbars and King 2004). Moreover, there is increasing acreage of corn in western Canada due to availability of low heat unit corn varieties. These crops are well adapted to the diverse growing conditions of the region. Agronomic practices for silage are generally similar to

that for grain production (Kaulbars and King 2004). Cereal crops are generally well ensiled due to high WSC content (Kaulbars and King 2004).

2.3.1 Barley

Barley is well adapted to most soil types in western Canada and responds well to soil fertility and moisture (Kaulbars and King 2004). Barley has a relatively low water requirement compared to corn and is tolerant of saline but not acid soils. Seeding rate of barley ranges from 85 - 140 kg ha^{-1} (Kaulbars and King 2004). Greater seeding rate increases the forage yield of barley under irrigated conditions (McKenzie et al. 2011). Dry matter yield of barley (3.9 t ha^{-1}) is comparatively lower than triticale (5.3 t ha^{-1}) or oats (4.1 t ha^{-1}) when harvested at early-dough (Baron et al. 2000). However, barley has a higher forage quality than either oats or triticale harvested at the same stage of maturity (Kaulbars and King 2004). These authors also reported that barley has a higher DM digestibility relative to oat and triticale at all stages from boot through to soft-dough. Barley for silage is commonly harvested in western Canada at mid-dough (Baron et al. 1992), in order to balance DM yield and nutrient quality. Addah et al. (2011) reported that barley silage harvested at mid-dough had greater CP (13.3 vs 9.6%) and lower starch content (25.9 vs 30.5%) relative to corn silage harvested at two-thirds milk line (% DM basis). These authors also reported that growing beef steers fed barley silage based backgrounding diets had greater DMI (7.1 vs 6.9 kg d^{-1}), ADG (1.43 vs 1.26 kg) and G:F (0.20 vs 0.18) than steers fed corn silage based diets. Greater ADF and NDF content of corn silage was proposed to be responsible for the poorer performance of steers fed corn silage diets.

Barley has superior forage quality among small grain species (Baron et al. (2000). Moreover, barley is easily ensiled due to low buffering capacity and high water-soluble

carbohydrate content (Acosta et al. 1991; Kaulbars and King 2004). However, there is variability among varieties within barley for forage quality (Baron et al. 2000). In an evaluation of spring and winter cereals for silage, these authors reported that a semi-dwarf barley variety (cv. Tukwa) had greater CP and *in vitro* digestible organic matter and lower ADF and NDF content than a standard barley variety (cv. Virden). Similarly, Khorasani and Kennelly (1997) reported that forage barley varieties varied in chemical composition and digestibility characteristics. These authors reported that the barley variety Seebe had lower ADF and NDF content relative to varieties like Duke and AC Lacombe. It was also reported that lactating dairy cattle fed a Seebe based diet had a relatively faster ruminal turnover rate and greater DMI than those fed the other varieties. However, detailed nutrient and digestibility parameters of common barley varieties grown for beef and dairy operations in western Canada has yet to be characterized.

2.3.2 Corn

Corn exhibits the highest yield among cereal crops in irrigated areas when heat units are not limiting. Corn generally has a lower CP content than barley. It is typically seeded at 75 000 plants ha $^{-1}$ with 15 cm space between seeds and 75 cm row spacing (Kaulbars and King 2004). Corn is harvested for silage at two-third milk line with a 30 - 40% DM content (Kaulbars and King 2004). It is easily ensiled due to an adequate (6-12%) WSC content (% DM basis) and low buffering capacity. The Brown-midrib (bmr) mutation in corn resulted in a lower lignin content and greater NDFD relative to isogenic corn (Kung 2011; Norell 2012). Saunders et al. (2015) reported that steers fed bmr corn silage based diets had greater ADG and feed efficiency (G:F) relative to those fed conventional corn silage based backgrounding diets. Moreover, these authors also reported that bmr corn silage based diets resulted in greater ruminal volatile fatty

acids (VFA), greater propionate and lower acetate:propionate concentration in steers relative to those fed conventional corn silage based diets.

2.3.3 Oats

Oats are more tolerant to acid but not to saline soils relative to barley or wheat (Kaulbars and King 2004). Oats are generally seeded at 73 - 129 kg ha $^{-1}$ (Kaulbars and King 2004) and harvested at soft-dough for silage (Bergen et al. 1991). These authors also reported that oat has a lower CP content and DM digestibility relative to barley and triticale. McCartney and Vaage (1994) reported a similar ADF and NDF content for oats harvested at milk and barley harvested at the soft-dough for silage. These authors also reported that growing beef heifers fed oat silage had similar DMI and lower ADG relative to those fed a barley silage based diet.

2.3.4 Triticale

Triticale has greater DM yield than barley or oats (Baron 2000) when harvested at milk or early-dough (Helm and Salmon 2002). Triticale is well suited for dryland conditions and has superior lodging resistance. Seeding rate of triticale is 95 - 146 kg ha $^{-1}$ (Kaulbars and King 2004). Triticale is a late maturing forage relative to barley and oats. It is generally harvested at boot or early-milk for silage (Kaulbars and King 2004). The CP and DM digestibility of triticale is intermediate between barley and oats (Kaulbars and King 2004). McCartney and Vaage (1994) reported that triticale harvested at early-dough for silage had greater ADF and NDF content relative to barley and oat ensiled at soft-dough ormilk, respectively. These authors also reported that growing beef heifers fed triticale silage had lower DMI and ADG relative to those fed barley or oat silage. Lower DMI of heifers fed triticale silage was attributed to poor palatability (McCartney and Vaage 1994).

2.3.5 Wheat

Wheat is relatively resistant to acid and saline soils. Seeding rate of wheat for silage ranges from 84 – 124 kg ha $^{-1}$ (Kaulbars and King 2004). Wheat is generally harvested at early-dough for silage. Kaulbars and King (2004) reported greater CP (12.2 vs 11.8%) and ADF (29.6 vs 26.5%) content for wheat forage at early-dough relative to barley forage at mid-dough (% DM basis). In an evaluation of small grain cereals for silage, Bergen et al. (1991) reported that freshly harvested whole crop wheat at milk and dough stages had greater DM yield and lower buffering capacity relative to oat or barley harvested at the same maturities.

2.4 Agronomic Characteristics of Barley

Barley has a lower water requirement than corn due to its early maturity and drought tolerance (Kaulbars and King 2004). Under irrigation, barley silage yield is highest if 375 - 450 mm of water is provided. Barley responds to higher seeding rate and N application in areas of high rain fall or irrigation (Kaulbars and King 2004). However, lodging is an issue for barley under high moisture and N fertilization conditions. Weeds and diseases can reduce barley yields by up to 15 - 20% (McKenzie 2008). Most common weeds of barley include wild oats, wild buckwheat and green fox tail. Control measures for weeds include herbicide application, crop rotation, increasing seeding rate and early seeding (McKenzie 2008). Most common diseases of barley include common root rot, net blotch and scald. Fungicides are generally applied to control fungal leaf diseases.

2.4.1 Types of Barley

Barley varieties can be classified according to number of rows of grain (2 row vs 6 row), hull adherence (hulled vs hulless) and presence of rough or smooth awns (awned, awnletted or

awnless). Barley can also be classified as feed or malting type, as well as tall (standard) or semi-dwarf. Standard type barley varieties yield more dry matter than semi-dwarf varieties under dry land conditions (Baron et al. 2000; Kaulbars and King 2004). Conversely, semi-dwarf varieties have excellent lodging resistance and are ideal for fertile land under irrigation (Kaulbars and King 2004). Baron et al. (2000) reported that semi-dwarf varieties had greater *in vitro* digestible organic matter and lower ADF and NDF content relative to standard barley varieties when harvested for silage at early-dough. In an evaluation of 2 row vs 6 row barley varieties in the Peace Region of Alberta, Gill et al. (2013) reported relatively greater DM yield (8449 ± 538 vs 7746 ± 367 kg ha^{-1}) and a lower NE_g content (1.09 ± 0.14 vs 1.15 ± 0.08 Mcal kg^{-1}) for 2 row relative to 6 row barley varieties.

2.4.2 Varieties of Barley

Common 2-row spring barley varieties grown for silage in western Canada include AC Metcalfe, CDC Austenson, CDC Coalition, CDC Copeland, CDC Cowboy, Champion, Conlon, Seebe and Xena. Two row hulless spring barley varieties include CDC Carter, CDC Fibar, CDC Freedom and Taylor. Six row spring barley varieties include AC Rosser, Celebration, Chigwell, Legacy, Sundre, Tradition and Virden. Six row hulless barley varieties include Falcon and Tyto. AC Metcalfe, CDC Copeland, Conlon, Taylor, Celebration, Legacy and Tradition are barley varieties selected for malting properties while AC Ranger and Dillon are forage type. Varieties like Conlon, AC Rosser, Celebration, Chigwell, Sundre, Virden, Falcon, Tyto and AC Ranger have smooth awns while Taylor, Legacy and Tradition have semi-smooth awns. All others have rough awns. Dillon is known as a hooded barley variety.

2.4.3 Seeding Time of Barley

Seeding barley from early May to early June resulted in higher whole plant yields in western Canada (Kaulbars and King 2004). McKenzie (2008) reported that early seeded barley is likely to receive longer periods of day light, early spring moisture and cooler temperatures resulting in greater crop yields. Similarly, late seeding (mid-June) reduced the period from sowing to emergence (7 d vs 13 d), vegetative period (43 d vs 48 d) and grain quality relative to seeding early May (Juskiw and Helm 2003). Moreover, delayed seeding reduced the grain yield in an evaluation of agronomic practices on yield of seven malting barley varieties (McKenzie et al. 2005). However, Chow et al. (2008) reported that the barley variety Vivar seeded in May and harvested at late-dough had a lower 30 h NDFD ($NDFD_{30h}$; % of NDF) relative to the same variety seeded in June and harvested at the same stage. It was concluded that even though average daily mean temperature was greater from planting to heading for the crop seeded in June relative to May, the lower average daily mean temperature from heading to harvestlikely resulted in lower lignification and improved $NDFD_{30h}$.

2.4.4 Seeding Rate of Barley

Spaner et al. (2001) proposed a seeding rate of 110 kg seeds ha^{-1} for barley above which these authors reported no improvement in grain yield. These authors also reported increasing plant height as seeding density increased from 85 to 160 kg seeds ha^{-1}. However, feed barley seeded at 170 kg seeds ha^{-1} resulted in greater grain yield relative to a seeding rate of 85 kg ha^{-1} (McKenzie 2008). The author also reported greater competitiveness with weeds at higher seeding rates. McKenzie et al. (2005) reported that the optimum seeding rate in non-irrigated areas is 85 kg seeds ha^{-1} while that for irrigated areas is 105 kg seeds ha^{-1}. These authors also reported that

high seeding rate will not compensate for late seeding. No improvement in grain yield was reported above the seeding rate of 125 kg seeds ha^{-1} with a modest increase when seeding rate was increased from 65 to 125 kg seeds ha^{-1} (McKenzie et al. (2005). These authors also reported that greater seeding rate increased the crop yield potential. Response to seeding rate was different under irrigated and non-irrigated conditions (McKenzie et al. 2011). Increased seeding rates increased the yields under irrigated conditions while lower than normal seeding rate was reported to increase the crop yield under dry conditions. O'Donovan et al. (2005) reported that increasing seeding rate for barley reduced the time to maturity but did not affect yield. These authors also reported that 23 cm row spacing resulted in greatest yield of barley whereas larger row space (30 cm) resulted in weed growth.

2.4.5 Nutrient Fertilization of Barley

Barley responds well to N fertilization due to its rapid growth and high yield potential (McKenzie et al. 2004). The N requirement of barley depends on soil nitrate-N, mineralization potential of soil, soil moisture and precipitation (McKenzie 2008). Plant height increased linearly as rate of top dressing with N increased from 0 to 60 kg N ha^{-1} (Spaner et al. 2001). However, these authors also reported greater lodging incidence with higher rates of N. Lodging rate increased from 13% with no top dressing to 84% with 60 kg N ha^{-1} (Spaner et al. 2001). Barley grown in soil with very low phosphorus (P) content responds well to P fertilization (McKenzie 2008). Other minerals included in fertilizers include potassium, sulphur and micronutrients including zinc, copper and manganese. McKenzie et al. (2005) reported that 7 malting varieties of barley responded similarly to N fertilization rates ranging from 0 to 160 kg N ha^{-1}. These authors also reported that N application was the most influential agronomic factor affecting yield and quality of malting barley. However, Anbessa and Juskiw (2012) reported that barley

cultivars had varying response to N application depending on variety. The cv. Tukwa and Noble having greater grain yield with increasing N application while cv. Manly showed a declining yield effect. It was concluded that a cultivar specific recommendation for N application is justified.

2.5 Growth Stages of Barley and Recommended Maturity at Harvest for Silage

Different barley growth staging systems are used to describe developmental stages of barley including the Zadoks, Huan and Feekes-Large staging systems. These systems help describe the major stages in barley development including germination, seedling establishment and leaf production, tillering, stem elongation, pollination, kernel development and maturity. Developmental stages of significance with respect to silage production ranges from the boot (Zadoks stage 40; Keleş et al. 2014) to hard-dough stages (Zadoks stage 85; Hargreaves et al. 2009).

2.5.1 Boot Stage (Zadoks Code 37 - 49)

During the boot stage (Zadoks code 37 - 49), the head becomes prominent within the flag leaf sheath (Anderson et al. 2013). The boot stage lasts for 7 - 10 d (Collar and Aksland 2001).

2.5.2 Head Emergence (Zadoks Code 50 - 60)

Flowering and pollination takes place during head emergence from the boot and lasts for 5 - 7 d. High temperatures and water deficiency at this stage reduces the number of kernels formed leading to lower grain yields. Seeding barley early in the season reduces the chances of yield loss due to environmental stress.

2.5.3 Milk Stage (Zadoks Code 73 - 79)

Kernel development begins after head emergence and pollination. Kernel size rapidly increases with only a modest increase in DM. The first stage of kernel development is the watery ripe and milk stage. A clear fluid can be squeezed from the developing kernel during the watery ripe stage with the color changing to milky-white as development progresses.

2.5.4 Early-dough Stage (Zadoks Code 81 - 83)

The milk stage is followed by the early-dough stage characterized by a white semi-solid consistency of the kernel. At the early-dough stage, the kernel is mostly soft and dry.

2.5.5 Mid/Soft-dough Stage (Zadoks Code 85)

During the mid-dough stage of kernel maturity, the water content in the kernel decreases so that the material pressed out of kernel is mostly a solid dough with the consistency of a meal. There is rapid accumulation of DM in the kernel at this stage and the color of kernel begins to fade from green to golden.

2.5.6 Hard-dough Stage (Zadoks code 87)

During hard-dough stage, the kernel reaches physiological maturity and has a solid kernel that is difficult to crush between fingers.

Timing of harvest for ensiling typically depends on subjective visual examination of these stages of maturity by producers (Baron et al. 1992). A review of literature indicated that barley can be harvested for silage at boot (Keleş et al. 2014), head elongation (Rustas et al. 2010; Wallsten and Hatfield 2016) milk (Rustas et al. 2009) or dough (early-, soft- or hard-dough) sHargreaves et al. 2009). Barley silage harvested at boot or vegetative stage is considered better

quality feed for high producing dairy cattle due to greater CP (Acosta et al 1991) content and DM digestibility (Kaulbars and King 2004) relative to harvesting at a later stage. However, barley is typically harvested at mid-dough stage of maturity in western Canada (Khorasani et al. 1997; Kaulbars and Kang 2004) for balancing DM yield and nutritive value of silage.

2.6 Effects of Maturity Stage on Nutrient Composition of Barley

2.6.1 Crude Protein and Protein Fractions

Crude protein content of whole crop barley generally decreases with advancing maturity (Khorasani et al. 1997; Wallsten et al. 2009). Borowiec et al. (1998) reported that whole crop barley for silage harvested at head emergence stage had greater CP content (10.4%) relative to that harvested at milk (9.4%) or dough (8.4%(% DM basis). Similarly, Wallsten et al. (2009) reported a decrease in CP content of whole crop 2 row (12.8 vs 11.1%) and 6 row (12.4 vs 10.0%) barley varieties when harvested at early-milk vs early-dough (% DM basis). Rosser et al. (2013) reported a quadratic decrease in CP content of the whole crop barley (cv. CDC Cowboy) with advancing maturity. These authors reported a decrease in CP content of barley forage from 18.5% at head elongation to 9.4% at full maturity (% DM basis). A similar decrease in CP content with advancing maturity of whole crop barley silage was reported by Hargreaves et al. (2009). These authors reported CP values of 9.8, 7.4, 7.6 and 6.7% CP (% DM basis) for silage samples taken at weekly intervals as barley for silage matured from head elongation to hard-dough.

Nadeau (2007) reported a relative decrease in ammonia-N (0.227 vs 0.207%) and total N (1.45 vs 1.24%) as whole crop barley silage matured from early-milk to early-dough when evaluated over 2 crop years. Bergen et al. (1991) reported greater (7.1 vs 4.9%; % total N basis)

acid detergent insoluble nitrogen (ADIN) for whole crop barley silage harvested at mid-dough relative to milk. The ADIN is the nitrogen fraction associated with the cell wall and is considered unavailable to the ruminal microbes, particularly in heat-damaged forages (Goering et al. 1972; Acosta et al. 1991). Greater ADIN with advancing barley maturity likely indicates greater cell wall deposition, lignification and lignin cross linking to hemicellulose as the plant matures, rendering cell wall components less available to the ruminal microbes.

2.6.2 Acid Detergent Fiber

The ADF fraction of forges includes cellulose and lignin and is negatively correlated to the digestibility of forages (Van Soest et al. 1978). Khorasani et al. (1997) reported that ADF content of whole crop barley showed a quadratic effect with advancing maturity. These authors reported that the ADF content increased with advancing maturity until about 3 wk after boot stage and then decreased. A similar observation was also reported by Mannerkorpi and Taube (1995) where ADF content of whole crop barley reached a maximum level at boot and then decreased as the plant reached full maturity. Wallsten et al. (2009) also reported a decline in ADF content of 6 row barley silage from 30.7% at boot to 27.7% at early-milk, which then plateaued at 26.3% ADF at early-dough. These authors also reported that the ADF content of 2 row barley silage decreased from 31.8% at early-milk to 28.0% at early-dough. Even though there is greater cell wall deposition and lignification with advancing maturity (Jung and Allen 1995), simultaneous starch deposition in kernels dilutes the concentration of cell wall components in the DM content of whole crop forages (Kaulbars and King 2004).

2.6.3 Neutral Detergent Fiber

The insoluble fiber fraction of forages is most conveniently measured as NDF (Van Soest et al. 1991) which includes cellulose, hemicellulose and lignin. Cellulose is the most abundant cell wall component and is composed entirely of glucose molecules linked by β 1-4 bonds (Jung et al. 2004). Hemicellulose is a group of polysaccharides composed of the sugar monomers glucose, xylose, arabinose, mannose and glucuronic acid (Jung et al. 2004) and is comprised of xylans, xyloglucans and mannans (Åman 1993). Lignin is a complex polymer of phenylpropane units that cross link to phenolic acids and other cell wall components. Lignin hinders the accessibility of forage cell wall polysaccharides to microbial enzymes (Jung et al. 2004).

Whole crop barley harvested at early-dough for silage had lower (% DM basis) NDF content (48.3 vs 55.8%) relative to that harvested at early-milk (Nadeau 2007). Similarly, Khorasani et al. (1997) reported a curvilinear relationship for forage NDF content with advancing maturity where the NDF content increased until head elongation and decreased thereafter. However, Rosser et al. (2013) reported a linear decrease in NDF content of whole crop barley (cv. CDC Cowboy) with advancing maturity as NDF content (% DM basis) decreased from 59.5% at boot to 50.0% at hard-dough. As described earlier, greater starch content with advancing maturity of whole crop barley dilutes the cell wall content of the plant.

2.6.3.1 NDF Digestibility

The NDF content (% DM basis) of barley ranges from less than 40 % (Addah et al. 2011) to over 60% (Dairy one forage lab, Ithaca, NY; 2016) depending on the stage of maturity at harvest. Availability of the cell wall components influences the digestibility of a given forage and thus dry matter intake and energy availability to the animal (Oba and Allen 1999; Hoffman and

Combs 2004). Studies with high NDFD corn varieties (i.e. brown mid-rib; bmr) have shown improved dry matter intake (DMI; Rook et al., 1977; Oba and Allen 1999b; Barrière et al., 2004) and milk yield (Oba and Allen 1999b; Ballard et al., 2001; Ebling and Kung 2004) in dairy cattle. Moreover, Oba and Allen (1999b) reported that a one-unit increase in NDFD is associated with 0.17 kg increase in DMI and 0.25 kg increase in 4% fat corrected milk in dairy cattle. These improvements in dairy cow performance were attributed to reduced ruminal fill, increased ruminal turnover of NDF and potential improvements in dietary energy status in cattle fed high NDFD forage (Mertens 1987; Oba and Allen 1999b; Oba and Allen 2000). Oba and Swift (2014) reported improved feed efficiency (kg milk per kg DMI) in dairy cattle fed a barley silage variety with a higher 30 h NDFD ($NDFD_{30h}$; cv. Falcon) relative to one with a lower $NDFD_{30h}$ (cv. Tyto). However, detailed information on $NDFD_{30h}$ of barley varieties commonly grown for silage in western Canada is lacking.

Barley cell wall degradability depends to a large extent on environmental factors and stage of maturity at harvest. An increase in lignification due to higher environmental temperature and/or increasing plant maturity reduces cell wall digestibility and the feeding value of forages (Kamstra et al. 1958; Fahey and Hussein 1999). Wallsten et al. (2009) reported a decrease in *in vivo* NDFD of barley silage as maturity at harvest advanced from heading to early-dough. Similarly, Hargreaves et al. (2009) reported a linear decrease in NDF digestibility of whole crop barley silage with advancing maturity

Most of the advanced mechanistic feed evaluation systems (CNCPS, CPM dairy; Van Amburgh et al., 2007; Tylutki et al., 2008) use digestibility of cell solubles and cell wall fractions (Traxler et al., 1998) for accurate prediction of DMI and performance of dairy cattle. The importance of NDFD lies in the fact that it influences the energy value of a forage and can

be used in calculations to provide a more accurate measure of TDN and NE by taking into account the digestibility of NDF and other nutrients (NRC 2001).

2.6.3.2 Physical Effectiveness of NDF

Physical characteristics of large fiber particles can impact ruminal fermentation and particulate passage rate, microbial protein synthesis, animal health and productivity (Mertens 1997; Yang and Beauchemin 2006). Physically effective NDF (peNDF) is the fraction of fiber that stimulates chewing activity and contributes to the rumen mat. The peNDF can be measured using the Penn State Particle Separator (PSPS) with 19mm, 8mm (Lammers et al. 1996) and 1.18 mm (Kononoff et al. 2003) screens. Particle sizes of 1.18 mm and above are considered to be physically effective for dairy cattle in that they effectively stimulate rumination and salivation (Mertens 1997). Increasing the theoretical chop length (TCL) increases the intake of physically effective fiber by cattle (Yang and Beauchemin 2006). A review of the literature indicated that increased intake of dietary peNDF increased the chewing activity, ruminal pH and milk fat content of dairy cows (Krause et al. 2003; Kononoff and Heinrichs 2003; Beauchemin and Yang 2005). However, Yang and Beauchemin (2006) reported that total tract digestibility of DM, OM, ADF and NDF decreased with increasing peNDF. These authors also reported that microbial protein synthesis and microbial efficiency were numerically greater for cattle fed low relative to those fed medium or high peNDF diets. In commercial production systems, the benefits of improved ruminal health and reduced incidence of ruminal acidosis by the greater peNDF content of the diet has to be weighed against the negative effect on total tract nutrient digestibility and microbial protein synthesis (Yang and Beauchemin 2006).

2.6.3.3 Dietary Energy from NDF

The cellulose and hemicellulose fraction of forage NDF are slowly digested in the rumen whereas lignin is considered indigestible (Jung and Deetz 1993; Weimer 1996). Dietary energy from NDF is a function of NDF content and its digestibility (NRC 2001). Accordingly, increased NDF digestibility results in greater TDN content of the forage. For example, Oba and Swift (2014) reported improved efficiency of milk production for dairy cattle fed a barley variety with higher (cv. Falcon) relative to low $NDFD_{30h}$ (cv. Tyto). These authors reported that greater NDFD of barley was associated with an increased energy supply to dairy cows without an increase in DMI. Moreover, Chow et al. (2008) reported increased BW gain for dairy cattle fed high $NDFD_{30h}$ barley silage. It was concluded that high $NDFD_{30h}$ of barley silage resulted in increased availability of dietary energy that was partitioned to BW gain. Forages with greater NDFD can be included at higher levels in the diet without compromising performance (Oba 2013). Moreover, high NDFD forages also provide flexibility in feed formulation and potentially reduce feed costs (Oba 2013).

2.6.3.4 *In Vitro* and *In Situ* Method for NDFD

Ruminal degradability of forages can be measured by the *in situ* nylon bag technique or by *in vitro* or *in vivo* methods. The *in situ* technique is not typically carried out commercially owing to variation between and within laboratories (Vanzant et al. 1998), lack of access to fistulated animals and higher labor costs. A simpler *in vitro* incubation technique ($Daisy^{II}$ system) developed by the Ankom Technology Corporation (Fairport, NY) allows for simultaneous incubation of a large number of samples. This method uses a $Daisy^{II}$ incubator where forage samples in individual Ankom bags are incubated in bulk containers rather than in individual

tubes as in other *in vitr* methods. Vogel et al. (1999) reported that both Daisy^{II} and conventional *in vitro* incubation techniques ranked different forage samples for *in vitro* dry matter digestibility in the same relative order. Similarly, Wilman and Adesogan (2000) and Damarian et al. (2008) reported that compared to other laboratory methods, Daisy^{II} incubation provided an accurate *in vitro* DM digestibility results in a shorter time frame with less labor.

Spanghero et al. (2003) reported that the Daisy^{II} incubations to assess *in vitro* digestibility were also repeatable and exhibited a higher correlation coefficient ($r^2 = 0.94$) for NDFD of first and second cut hay samples as compared to the *in situ* procedure (Table 2.1). Similarly, Damarian et al. (2008) reported greater spearman correlation coefficients for NDF digestibility estimates ($r^2 = 0.88$) between Daisy^{II} incubation and *in situ* methods.

Table 2. 1. Comparison of NDF digestibility of hay samples by *in situ* and Daisy^{II} methods

		Method	
Sample type	Fertilization[a]	*In situ*	Daisy^{II}
Hay (n = 18)			
First cut	1	37.6	44.0
	2	40.1	44.3
Second cut	1	41.7	47.8
	2	42.6	51.9

Note: Spanghero et al. (2003).

[a]NDF digestibility of first and second cut hay grown under either slurry or slurry plus mineral N application fertilization system and measured by *in situ* and by 48 h Daisy^{II} incubation.

2.6.3.5 Lag Time

Ruminal microbial fiber digestion is brought about by the complex interaction between forage, ruminal microbial and animal factors (Varga and Kolver 1997). These authors reported that fiber digestion begins with the attachment and colonization of ruminal microbes to the forage particles. The period of time required for microbial fiber digestion to begin represents the lag time and depends on availability of attachment sites on forage, mass and species composition of fibrolytic bacteria in the rumen and the ability of microbes to attach to fiber in the rumen (Allen and Mertens 1988; McAllister et al. 1994). Forages have been reported to have varying lag times (Spalinger 1985; Moore and Cherney 1986) with Van Soest et al. (2005) reported that a 6 h fermentation best describes lag time.

2.6.3.6 *In Vitro* Incubation 30 vs 48 h

NDF digestibility can be determined after 24, 30 or 48 h of *in vitro* incubation (Hall 2015). Incubation for 30 h represents the normal residence time of NDF in rumen of high producing cattle (Oba 2013). However, Hoffman et al. (2003) reported that NDFD values are less repeatable when shorter incubation times (24 h) are used and hence may underestimate TDN. These authors also reported that incubations over 48 h iare more repeatable. However, 48 h incubations may slightly over predict NDFD and thereby TDN content of the forage. These authors reported a strong correlation ($r^2 = 0.82$) between 30 and 48 h NDFD. Hall (2015) reported that 30 h NDFD correlates to differences in lag time or the rate of fermentation between forages whereas 48 h NDFD best describes the extent of digestion. Oba and Allen (2011) reported that 30 h *in vitro* NDFD correlates to the normal ruminal retention time for forage NDF.

Moreover, Hoffman and Combs (2004) reported that 30 h *in vitro* NDFD values better represent *in vivo* NDFD at maintenance.

2.6.3.7 Indigestible NDF Content

Indigestible NDF is that fraction of forage NDF that is not available to the ruminal microbes and contributes no usable energy to the animal. Indigestible NDF is used as an indicator of forage digestibility and is used for digestible energy predictions in mechanistic feed evaluation models (Krämer et al. 2012; Krizsan and Huhtanen 2013). Hill (2015) reported that INDF is used for predictions of DMI as undigested fiber limits intake through gut fill. Indigestible NDF is determined either by *in vitro* or by *in situ* ruminal incubation. Durations of *in vitro* incubations assessed include 96 (Huhtanen et al. 1994), 144 (Traxler et al. 1998) or 240 h (Raffrenato and Erasmus 2013). Duration of ruminal *in situ* incubation of feed samples has been reported to be 240 or 288 h (Jancik et al. 2008; Krizsan et al. 2012). A review of literature indicated that the pore size of *in situ* bags used was either 6 (Huhtanen et al. 1994), 12 (Krizsan et al 2012), 17 (Jancik et al. 2008) or 41 µm (Huhtanen et al. 1994). Results indicate that INDF content is affected by the method of incubation, pore size of the *in situ* bag and duration of incubation (Huhtanen et al. 1994).

2.6.4 Lignin

Lignin is a non-carbohydrate polymer composed of phenolic units that forms cross links to the components of the forage cell wall. Lignin biosynthesis involves production of monolignols (*p*-Coumaryl alcohol, Coniferyl alcohol and Sinapyl alcohol), transportation of monolignols across plasma membrane to the apoplast and polymerization of monolignols to complex lignin polymers (Frei 2013). The phenolic acids, ferulic acid (FA) and *p*-coumaric acid are the major phenolic

compounds that cross link with cell wall structural carbohydrates and to lignin (Addah et al. 2012b). Ferulic acid is the most abundant phenolic acid in the cell walls of cereals (Bartolomé et al. 1997). Ferulic acid binds to arabinoxylans and glucuronoarabinoxylans of hemicellulose. Moreover, these phenolic compounds cross link cell wall polysaccharides to each other. Ferulic acids are also linked to lignin, further reducing forage cell wall digestibility (Addah et al. 2012b).

Lignin content of barley depends on the growth stage and environmental conditions. Khorasani et al. (1997) reported a modest increase in lignin content with advancing maturity of barley. These authors reported that as maturity of barley increased, the lignin content modestly increased until 2 wk after boot stage and decreased thereafter. Similarly, Mannerkorpi and Taube (1995) also reported that the lignin content of whole crop barley increased until head emergence and plateaued thereafter as plant maturity increased from boot to full maturity. Similar to other cell wall components, the lignin content (% DM basis) decreased with advancing plant maturity as greater starch accumulates in the seed head (Wallsten and Hatfield 2016).

Lignin is indigestible in the rumen and moreover, hinders the accessibility of forage cell wall polysaccharides to microbial enzymes (Jung et al. 2004). Lignin is negatively correlated to forage digestibility (Buxton and Russell 1988; Jung and Deetz 1993). Greater lignification and cross linking with cell wall polysaccharides with advancing plant maturity makes cell wall components unavailable for ruminal microbial fermentation (Jung and Deetz 1993). The extensive cross linking of FA to cell wall polysaccharides and lignin decreases the cell wall digestibility and nutritive value (Yu et al. 2005). Third generation silage inoculants with ferulic acid esterase activity has been shown to break the ferulic acid bond with cell wall polysaccharides resulting in improved susceptibility of forage cell wall to microbial degradation in the rumen (Yu et al. 2005). Moreover, Addah et al. (2012a) reported that whole crop barley

silage inoculated with a third-generation ferulic acid esterase inoculant improved ensiling and aerobic stability of silage the feed efficiency of growing steers.

2.6.5 Starch

Starch content of whole crop barley increases with advancing barley maturity. Nadeau (2007) reported a significant increase in starch content (33.8 vs 3.8%; % DM basis) when barley was harvested at early-dough relative to early-milk. Similarly, a greater increase in starch content was also reported by Wallsten et al. (2009) with advancing maturity of whole crop barley. These authors reported starch content (% DM basis) of 5.0% at head elongation, 7.4% at early milk and 20.5% at early-dough for six row whole crop barley. It was also reported that starch content of two row barley increased from 1.0% at early milk to 16.9% at early-dough. Starch is generally not utilized by microbes during silage fermentation. However, acid hydrolysis of starch at lower silage pH may release simple sugars (Wallstern et al. 2008).

2.7 Factors Affecting Silage Quality

The process of ensiling depends on the complex interaction between the forage being ensiled, microbial population and the ensiling conditions (McAllister and Hristov 2000). Major objectives of ensiling are to preserve the nutrient composition of the forage and to minimize the DM and energy losses during ensiling (Muck 1988).

2.7.1 Forage Factors

Forage factors including DM, WSC, CP and epiphytic microbial population of barley affect the fermentation process. The DM content of barley is affected by the stage of maturity at harvest and environmental growing conditions. Recommended DM content for barley silage is 30 - 40%

(Baron et al. 1992; Baron et al. 2000) with some authors reporting up to 45% (Hargreaves et al. 2009).

Water soluble carbohydrates are the most readily available source of energy for the epiphytic microbes (McAllister and Hristov 2000). Whole crop barley is easily ensiled due to its high water soluble carbohydrate content and low buffering capacity. Barley forage harvested at mid-dough for silage has 10 - 20% WSC which can act as a substrate for lactic acid production during ensiling (McAllister et al. 1995).

Epiphytic microorganisms are associated with the forage at the time of ensiling. The number of epiphytic microbes generally decreases with advancing maturity of forage. McAllister and Hristov (2000) reported that the type of lactic acid bacteria in the forage rather than the total number of bacteria has a major role in the success of the ensiling process. Barley forage has been reported to have a lower epiphytic bacterial population relative to corn (Addah et al. 2011).

McDonald et al. (1991) reported that the majority of the buffering capacity of forage is exerted by organic acids with the remaining by plant proteins. The buffering capacity of corn silage is lower than that of barley while the crude protein content of legumes is greater than that of cereal forages leading to greater buffering capacity in legumes than cereals.

2.7.2 Silage Volatile Fatty Acids and Lactic Acid

Lactic acid is the primary fermentation acid in well preserved silages. Lactic acid is primarily responsible for the drop in the silage pH during ensiling. Homolactic bacterial inoculants produce mainly lactic acid, resulting in a rapid drop in silage pH. Moreover, homolactic fermentation reduces the DM loss during ensiling (McDonald et al. 1991). A high DM content of ensiled forage results in restricted fermentation and lower levels of lactic acid. It is generally

accepted that in well preserved silages, lactic acid constitutes 65 -70% of the total silage acids produced.

Forages harvested at early growth stages (ie. milk vs soft-dough) result in more lactic and acetic acid in silage. Bergen et al. (1991) and Borowiec et al. (1998) reported greater lactic acid concentration in after ensiling of barley at milk as compared to soft-dough. Moreover, heterolactic fermentation results in relatively greater acetic acid concentrations in silage. Higher acetic acid levels impart greater aerobic stability to silage during the feed-out phase as this acid inhibits yeasts and molds. However, DM recovery is relatively lower with acetic acid production relative to lactic acid fermentation (McDonald et al. 1991). Well preserved barley silages generally have low levels of propionic acid. A high concentration of butyric acid in silage indicates spoilage as a result of clostridial fermentation. High butyric acid (> 5%) concentrations in silage reflects a lower nutritive value, adversely affecting animal performance.

2.7.3 Silage pH

A final silage pH of 3.8 - 4.2 indicates well preserved cereal silage (Kaulbars and King 2004). It is generally accepted that the lower the pH the better the silage quality, as the lower pH indicates that the fermentation process was such that sufficient fermentation acids were produced to prevent microbial activity and impart silage stability. Silage pH depends on the amount of fermentation acids produced and also the buffering capacity of the ensiled forage (Kung 2010). A silage pH of 4.2 (Kaulbars and Kang 2004) to 4.4 (Acosta et al. 1991) or lower indicates a desired lactic acid type fermentation and preservation of nutrients. A faster drop in silage pH as occurs with homolactic fermentation also promotes silage quality. A higher DM content of

ensiled forage usually results in silage with a higher pH as there is low concentrations of WSC available for conversion to lactic acid.

2.7.4 Aerobic Stability

Aerobic stability is defined as the duration of time that silage temperature remains at 1ºC (Driehuis et al. 1999) to 2ºC (Kung et al. 2004) below the ambient temperature when exposed to air during storage and feedout. Factors affecting aerobic stability include type and population of spoilage microorganisms in the silage, amount of residual WSC and lactate and presence of spoilage inhibitors like acetic, propionic and butyric acid (Woolford et al. 1990; McAllister et al. 1995; Addah et al. 2013). Aerobic deterioration of silage is brought about by the utilization of residual WSC and/or lactate by the yeast population in silage during the feed-out stage (Woolford 1990). A concentration of 5 $\log_{10}$ CFU g^{-1} of yeast is reported to be the threshold population for silage deterioration (Woolford 1990). Muck and Pitt (1994) reported that enterobacteria are capable of initiating aerobic deterioration of corn silage. Initiation of silage spoilage is indicated by an increase in silage pH and temperature (McAllister et al. 1995). The DM loss due to poor aerobic stability of silage is reported to be as high as 30% (McDonald et al. 1991). Management practices for reducing the aerobic deterioration of silage include maintaining the recommended packing density during silo filling, covering the silo to maintain anaerobic conditions and good silo face management and feed out practices (McAllister and Hristov 2000). First generation silage inoculants (homolactic fermenters) have been reported to negatively affect the aerobic stability of silage due to greater production of lactic acid and conservation of WSC. These substrates are utilized by spoilage microorganisms during aerobic deterioration of silage (Addah et al. 2013). However, second generation silage inoculants (heterolactic fermenters) result in a greater proportion of acetic- and propionic acid during ensiling. These end products of

silage fermentation have antimicrobial properties that improve the aerobic stability of silage during the feed out phase. Greater packing density has also been reported to improve aerobic stability during the feed-out phase (Ruppel et al. 1995).

2.8 Value of Barley Silage in Feedlot and Dairy Diets

Addah et al. (2011) reported that feedlot steers fed barley silage based backgrounding diets had greater ($P < 0.05$) DMI (7.1 vs 6.8 kg), ADG (1.42 vs 1.25 kg d^{-1}) and G:F (0.20 vs 0.18) relative to steers fed corn silage based diets. Both diets had 60:40 forage:concentrate ratios (% DM basis). Improved feedlot performance of steers fed barley silage-based diets was attributed to its greater CP and lower ADF content relative to corn silage. McCartney and Vaage (1994) reported that beef heifers fed barley silage-based backgrounding diets had greater end trial BW (381 kg) relative to those fed triticale (362 kg) or oat (370 kg) based silage diets. Moreover, DMI of heifers fed barley silage-based diets was greater (6.1 kg d^{-1}) relative to those fed triticale (4.9 kg d^{-1}) or oat (5.7 kg d^{-1})- based silage diets. Improved performance of beef heifers fed barley silage-based diets was attributed to greater DM, OM, CP and NDF digestibility of barley as compared to oat or triticale silage.

2.8.1 Level of Inclusion of Barley Silage on Beef and Dairy Cattle Performance

In an evaluation of the effect of the barley silage:concentrate ratio on beef cattle performance, Hironaka et al. (1994) reported that steers fed 75:25 F:C ratio had lower ADG (1.04 vs. 1.51 kg), DMI (9.5 vs. 10.3 kg d^{-1}) and G:F (0.110 vs. 0.145) relative to those fed a 58:42 F:C diet. Chibisa et al. (2016) reported that steers had higher DMI (11.1 vs 8.2 kg d^{-1}) when fed a low (30:70 forage:concentrate) relative to a high (70:30 forage:concentrate) barley silage diet. Acosta et al. (1991) reported that mid-lactation dairy cattle fed 60:40 relative to 75:25 barley

silage:concentrate diets had greater 4% fat corrected milk yield (24.5 vs 22.6 kg d^{-1}). A slight increase in level of inclusion of barley silage in feedlot diets especially during finishing is beneficial in reducing the risk of ruminal acidosis (Koenig and Beauchemin 2011). However, greater barley silage in finishing diets negatively affects feed efficiency (Koenig and Beauchemin 2011). There is potential to include a forage with greater NDFD in the diets of high producing ruminants without compromising production potential (Oba 2013).

2.8.2 Maturity at Harvest of Barley on Beef and Dairy Cattle Performance

Acosta et al. (1991) reported that mid-lactation dairy cattle fed barley silage harvested at boot stage resulted in numerically greater 4% fat corrected milk yield (24.0 vs 22.8 kg d^{-1}) relative to those fed barley silage harvested at soft-dough stage at similar DMI (16.4 kg d^{-1}). These authors attributed improved efficiency of milk production (1.68 vs 1.53 kg milk kg^{-1} DMI) to greater digestibility of barley silage harvested at boot relative to soft-dough. Wallsten and Martinsson (2009) reported a linear decrease in DMI and milk yield in dairy cattle when maturity at harvest of whole crop barley advanced from heading to early-dough. Rustas et al. (2009) reported greater DMI and ADG for steers fed barley silage harvested at mid-dough as compared to early-milk. These authors attributed the lower (45.9 vs 54.4%) NDF content (% DM basis) of barley silage harvested at mid-dough relative to early-milk for the improved performance of steers.

2.8.3 Maturity at Harvest of Barley on Nutrient Digestibility

Acosta et al. (1991) reported that growing heifers fed barley silage harvested at boot had greater apparent total tract DM, OM, CP, ADF and NDF digestibility relative to those fed barley silage harvested at soft-dough. Wallsten and Martinsson (2009) and Wallsten et al. (2009) reported a

linear decrease in total tract digestibility of dietary DM, OM and NDF of whole crop barley as it was harvested and ensiled from heading to early-dough.

2.8.4 Level of Inclusion of Barley Silage on Nutrient Digestibility

Hironaka et al. (1994) reported higher ADF digestibility for steers fed a TMR containing barley silage and barley-based concentrate in the ratio of 3:1 relative to 1:1 (% DM basis). They reported a curvilinear response in nutrient digestibility depending on the level of concentrate in the diet. Similarly, Soita et al. (2003) reported greater DM, ADF, NDF and CP digestibility for steers fed barley silage-based diets with 1:4 relative to 1:1 forage:concentrate ratio (% DM basis).

2.8.5 Level of Inclusion of Silage on Ruminal pH and VFA Concentrations

Chibisa et al. (2016) reported a higher ruminal pH (mean, minimum and maximum) and lower duration and area under pH threshold 5.8 and 5.5 for steers fed a high (70:30 forage:concentrate) relative to low (30:70 forage:concentrate) barley silage-based diet. These authors also reported greater total VFA concentration for steers fed low relative to high barley silage-based diets. Greater VFA and lower ruminal pH parameters were attributed to the greater availability of readily fermentable carbohydrates in the low silage based diets.

2.8.6 NDF Digestibility and Milk Production

Oba and Allen (1999) reported that a one-unit increase in NDF digestibility was associated with 0.17 kg increase in DMI and 0.25 kg increase in 4% fat corrected milk yield in dairy cattle. It should be noted that these findings are based on research on NDFD of corn silage. Similar studies using barley varieties with varying NDFD is lacking. Acosta et al. (1991) reported no

difference in DMI or milk yield in dairy cattle fed whole crop barley silage harvested at boot or soft-dough in forage:concentrate ratios (% DM basis) of 75:25 or 60:40. There was a numerical decrease in DMI (16.2 vs 16.6 kg) and increase in milk yield (24.0 vs 22.8 kg d^{-1}) for cows fed barley silage harvested at boot as compared to soft-dough (Acosta et al. 1991). These authors reported that apparent total tract digestibility of CP, ADF and NDF was greater for barley silage harvested at boot than soft-dough. Greater NDF digestibility is positively correlated to improved DMI and milk production in dairy cattle (Oba and Allen 1999).

2.8.7 NDF Digestibility and Feedlot Performance

Finishing feedlot steers are at risk of developing acute ruminal acidosis owing to greater content of grain in the diet. Barley forages with greater NDFD allow for a greater inclusion of forage at equal energy density allowing for a reduction in metabolic disorders and possibly feed costs. Greater NDFD is also correlated to greater TDN content and availability of dietary energy (Hoffman and Combs 2004). Consequently, barley forage varieties with higher NDFD potentially allow for a greater inclusion of forage in the backgrounding and finishing diets without compromising the potential of high producing animals (Oba 2013).

2.8.8 Stage of Maturity at Harvest on Dry Matter Intake

Mertens (1994) reported that the performance of ruminants is correlated to DMI. Wallsten et al. (2009) reported that *ad libitum* DMI of dairy cattle fed whole crop barley silage harvested at heading, early-milk or early-dough showed a linear ($P < 0.01$) decrease with advancing maturity. These authors also reported that NDF intake also quadratically declined as the plant matured ($P < 0.01$). Huhtanen et al. (2007) and Wallsten et al. (2009) reported that harvesting of whole crop cereals at heading or early-milk likely results in lower DM content post-ensilng and together

with the fermentation end products lower DMI in feeding trials. Volatile fatty acids from silage fermentation, especially acetic acid, have been negatively correlated to DMI in sheep and cattle (Wilkins et al. 1971; Gill et al. 1988). However, a review of the literature indicated that acetic acid in silage by itself may not depress DMI (Hutchinson and Wilkins et al. 1971; Taylor et al. 2002). In fact, badly-preserved silages generally have greater concentrations of acetate along with other metabolites produced by spoilage microorganisms like biogenic amines, amides and other nitrogenous end products which are often associated with depressed DMI (McDonald et al. 1991; Seglar 2003).

2.8.9 Green Feed vs Silage Barley

The quality of forage is not generally improved by ensiling (Juskiw et al. 2000). Hence it is important to ensile high-quality forage and follow good ensiling practices to optimize the quality of the forage conserved. Well preserved silage can maintain the quality of forage used for ensiling. However, fresh forage and the resulting silage may differ in CP and WSC content (Kaulbars and King 2004). Silage may contain less WSC than fresh forage. However, there have been reports where the WSC in silage was greater than that in fresh forage (Addah et al. 2011). Acid hydrolysis of plant cell wall may result in the release of simple sugars that could contribute to the greater WSC in silages (Wallsten et al. 2008). Further, a fraction of protein in fresh forage is converted to nonprotein-nitrogen (NPN) during ensiling. Moreover, protein degradation products in poorly preserved silage like biogenic amines negatively affect DMI. However, well preserved silage has DE content similar to that of fresh forage (Kaulbars and King 2004).

2.9 Improving the NDF Digestibility and Forage Value of Barley Silage

Silage quality and NDF digestibility of whole crop barley can be improved by optimizing the stage of maturity at harvest and possible genetic selection and plant breeding. The addition of additives such as silage inoculants or enzymes at ensiling may also improve silage quality.

2.9.1 Harvest Maturity

Whole crop barley is generally harvested at mid-dough so as to balance DM yield and nutrient quality (Baron et al. 1992; Kaulbars and King 2004). However, studies (Acosta et al. 1991) with lactating dairy cattle fed whole-crop barley harvested at boot relative to soft-dough had greater 4% fat corrected milk (24.0 vs 22.8 kg d^{-1}) and efficiency (kg milk kg^{-1} DMI) of milk production (1.68 vs 1.53). Greater NDFD of barley at boot as compared to soft-dough was reported by these researchers. Similarly, Wallsten and Martinsson (2009) reported a linear decrease in DMI, milk yield and efficiency of milk production in dairy cattle as maturity at harvest of whole crop barley silage advanced from heading to soft-dough. These authors reported a decrease in NDFD of barley silage from head elongation to early-milk (Wallsten et al. (2009). However, Rustas et al. (2009) reported that feedlot steers fed whole crop barley silage harvested at mid-dough had greater DMI and ADG relative to those fed barley silage harvested at early-milk. It could be inferred that the optimum stage of maturity at harvest in order for barley silage to improve dairy cattle performance is slightly earlier than the current recommendation of mid-dough. There is potential for harvesting barley at maturities other than the conventional mid-dough stage for improved animal performance (beef vs dairy).

2.9.2 Third Generation Silage Inoculants

Third generation silage inoculants have ferulic acid esterase activity, thereby exhibiting the potential to enhance the fiber digestibility of silage. Ferulic acid esters have a negative effect on cell wall digestion because its involved in forming linkages between hemicellulose and lignin (Addah et al. 2012b). Krueger et al. (2008) reported that application of a ferulic acid esterase enzyme increased the release of WSC from forages. Moreover, these authors reported greater *in vitro* and *in situ* degradation of hay with the addition of this enzyme. Similarly, greater 48 h NDFD was reported for both corn (Nsereko et al. 2008; Kang et al. 2009) and whole crop barley (Addah et al. 2012) silage inoculated with a ferulic acid producing third generation inoculant. This study also reported a greater feed efficiency (G:F) in steers fed inoculated whole crop barley silage (Addah et al. 2011, 2012) relative to those fed uninoculated barley silage.

2.9.3 Exogenous Fibrolytic Enzymes

Exogenous fibrolytic enzymes are added either at the time of ensiling or mixed directly with the forage,concentrate or TMR at the time of feeding (Beauchemin et al. 1997; McAllister et al. 1999; Kung 2014). Fibrolytic enzymes may help improve silage fermentation by degrading structural carbohydrates to simple sugars which serve as substrates for LAB. Moreover, partial degradation of forage cell wall by enzymes likely improves the digestibility of the resultant silage (Kung 2014). Cellulase, hemicellulase and xylanase are the common plant fiber digesting enzymes generally used in combination with inoculants. The enzyme amylase degrades starch to sugars. Efficiency of enzyme additives depends on forage type, enzyme type and application rate, LAB population, forage type and silage pH and temperature (Kaiser 2005). Generally, enzyme inoculants are active at a temperature of 50ºC while the optimum pH for most cellulases

and amylases is 4.5 and 6.0, respectively (Kaiser 2005). Similarly, enzyme activity increases with increasing temperature and decreases with increasing DM content of forage (Kaulbars and King 2004).

McAllister et al. (1999) reported that backgrounding steers fed whole crop barley silage had similar DMI, ADG and feed efficiency relative to steers fed barley silage where silage was sprayed at feeding with graded levels of a fibrolytic enzymes. However, there was a quadratic increase in DMI and feed efficiency and a tendency for quadratic increase in ADG during the first 56 d of backgrounding. These authors also reported that during finishing, steers fed TMR sprayed with the enzyme mixture had greater ADG relative to those fed uninoculated silage. Similarly, Beauchemin et al. (1997) reported a numerically greater ADG (1.52 vs 1.43 kg d^{-1}) and significantly better F:G (6.3 vs 7.1) for steers fed an enzyme treated barley silage based finishing diets at the time of feeding relative to steers fed a control diet. However, Beauchemin et al. (2003) and Adesogan et al. (2014) both reported that the impact of addition of exogenous enzymes on animal performance has been inconsistent. These authors reported that factors like enzyme activity, enzyme application rate, method of enzyme application and physiological status of the animal affect the value of enzyme application.

2.9.4 Plant Breeding and Selection

A review of literature indicated that there is considerable amount of information available on the effect of feeding high NDFD corn varieties (i.e. brown mid-rib; bmr) on animal performance (Oba and Allen 1999b; Ballard et al. 2001; Ebling and Kung 2004). It has been reported that bmr corn improved dry matter intake (DMI; Rook et al. 1977; Oba and Allen 1999b; Barrière et al. 2004) and milk yield (Oba and Allen 1999b; Ballard et al. 2001; Ebling and Kung 2004) in dairy

cattle. However, there has not a paucity of research conducted on selection of barley varieties for high NDFD. In a recent evaluation of feeding 6 row hulless barley silage varieties varying in $NDFD_{30h}$ on dairy cattle performance, Oba and Swift (2014) reported that cows fed a barley variety (Falcon) with greater $NDFD_{30}$ (61.6 vs 57.2%) resulted in improved efficiency of milk production relative to those fed a variety (Tyto) with a lower $NDFD_{30}$. These authors reported that higher $NDFD_{30h}$ of Falcon resulted in greater availability of dietary energy without increasing DMI.

2.10 Conclusion

Barley varieties commonly grown for silage in western Canada by beef and dairy producers vary in nutrient composition and digestibility. High NDFD forages (ie. bmr corn) have been reported to improve DMI and milk yield in dairy cattle. Improved performance of cattle fed high NDFD forages is attributed to a faster ruminal disappearance of forage NDF, allowing for greater DMI. There has not been a great deal of research conducted on the effect of feeding whole crop barley varieties with $NDFD_{30h}$ on backgrounding and finishing performance of feedlot steers.

2.11 Hypothesis

The hypothesis of this research is that barley silage varieties with higher $NDFD_{30}$ will result in an increased ruminal degradation of forage cell wall components resulting in greater ruminal particulate passage rate, increased availability of dietary energy, higher DMI, increased ruminal pH and improved performance of backgrounding and finishing cattle relative to steers fed barley silage varieties with a lower $NDFD_{30}$.

2.12 Objectives

1. Evaluate the nutrient composition and the extent of 6 and 30 h NDFD of common barley varieties grown for silage by beef and dairy producers in western Canada.
2. Evaluate variety differences in indigestible NDF (INDF) content of barley varieties.
3. Evaluate the effects of ensiled barley varieties that were previously shown to vary in $NDFD_{30h}$ when fed at two inclusion levels in backgrounding and finishing diets on performance and carcass characteristics.
4. Evaluate the effect of feeding barley varieties previously shown to vary in $NDFD_{30h}$ and the level of inclusion on ruminal fermentation and particulate passage rate, total tract digestibility characteristics and digestible energy content for growing beef heifers fed backgrounding and finishing diets.
5. Evaluate the effects of variety and stage of maturity at harvest on $NDFD_{30h}$ as well as nutrient composition of barley green feed with advancing maturity from milk to hard-dough stage.

3.0 A Nutritional Evaluation of Common Barley Varieties Grown for Silage by Beef and Dairy Producers in Western Canada

3.1 Abstract

This study evaluated the nutritional and neutral detergent fiber digestibility (NDFD) characteristics of seven barley varieties (Conlon, CDC Copeland, CDC Cowboy, Falcon, Legacy, AC Metcalfe and Xena) grown for silage. Commercial samples (N = 80) harvested at the mid-dough were collected over two years (2012 and 2013). Average pH and dry matter (DM) content were 4.05 ± 0.17 and 36.8 ± 4.1%. Falcon and AC Metcalfe had higher ($P < 0.05$) CP relative to CDC Copeland and Xena with intermediate values for the other varieties. Acid (ADF) and neutral (NDF) detergent fiber content were higher ($P < 0.05$) for CDC Cowboy relative to Conlon. Starch was higher ($P < 0.05$) for Legacy and Conlon than CDC Cowboy with intermediate values for other varieties. Legacy and Falcon had a greater $NDFD_{6h}$ (% NDF basis) while CDC Cowboy had a greater $NDFD_{30h}$ (% NDF basis) among the barley varieties evaluated. Indigestible NDF (INDF; % of NDF) was greater ($P < 0.05$) for AC Metcalfe relative to CDC Cowboy and Falcon. These results indicate that barley varieties vary with respect to chemical composition, NDFD and INDF content. Selection for higher $NDFD_{30h}$ could result in improvements in DM and DE intake and performance.

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Key Words: Barley silage, chemical composition, *in vitro* NDF digestibility, indigestible NDF, Daisy^{II}

3.2 Introduction

Whole-crop barley (*Hordeum vulgare* L.) silage is the principal forage source for feedlot and dairy operations in western Canada (McAllister et al. 1995; Hristov and McAllister 2002). More than 250 varieties of barley are grown in Canada. These varieties can be classified in a number of different ways, including tall (standard) vs semi-dwarf; feed vs malting; two row vs six row; hulled vs hulless or having smooth awns vs rough awns (Canadian Food Inspection Agency 2015). Despite the importance of barley silage in ruminant diets, producers are often faced with a lack of information on which variety to grow for silage, particularly from the perspective of nutritional quality. Hence, when making variety selections, producers tend to place more emphasis on yield and other agronomic characteristics like disease and lodging resistance rather than on the nutritional value of the forage.

One area where barley breeding holds promise is to select silage varieties for high neutral detergent fiber (NDF) digestibility (NDFD). Neutral detergent fiber content of barley silage ranges from less than 40% (Addah et al. 2012a) to above 60 % (% DM; Dairy one forage lab, Ithaca, NY) depending upon stage of maturity at harvest. Ruminal and total tract digestibility of NDF is lower than that of non-structural carbohydrates such as starch (Huhtanen et al. 2006). Studies with high NDFD corn varieties (i.e. brown mid-rib; bmr) have shown improved dry matter intake (DMI; Rook et al. 1977; Oba and Allen 1999b; Barrière et al. 2004) and milk yield (Oba and Allen 1999b; Ballard et al. 2001; Ebling and Kung 2004) in dairy cattle. These improvements in dairy cow performance were attributed to reduced ruminal fill, increased ruminal turnover of NDF and potential improvements in dietary energy status in cattle fed the

high NDFD forage (Mertens 1987; Oba and Allen 1999b; Oba and Allen 2000). As well, Oba and Swift (2014) reported no improvement in DMI or milk yield but better feed efficiency (kg milk per kg DMI) in dairy cattle fed a barley silage variety with a higher 30 h NDFD ($NDFD_{30h}$; cv. Falcon) relative to one with a lower $NDFD_{30h}$ (cv. Tyto). With respect to beef cattle, to the author's knowledge there has been very little research that has examined the $NDFD_{30h}$ characteristics of barley silage and the potential differences that may exist among varieties.

Most advanced mechanistic feed evaluation systems (CNCPS, CPM dairy; Van Amburgh et al. 2007; Tylutki et al. 2008) calculate forage energy values on the basis of digestible cell solubles and cell wall fractions (Traxler et al. 1998). The indigestible fraction of NDF (INDF) is not available to ruminal microbes and contributes no usable energy to the animal. In newer versions of mechanistic feed evaluation models, INDF is being evaluated to improve the prediction of total NDF digestibility and the accuracy of balancing ruminant diets (Harper and McNeill 2015). This research suggests that selection pressure by plant breeders for increased NDFD may result in new or improved barley forage varieties that allow producers to select varieties with enhanced nutritional as well as agronomic qualities.

This study involved collection of barley silage samples and key agronomic information over two crop years from beef and dairy producers in Saskatchewan and Alberta. The objective was to compare varieties that are grown by cattle producers for nutrient composition as related to modern feed formulation systems (CNCPS, CPM dairy) and to determine variety differences on the extent of 6 and 30 h NDFD and INDF content.

3.3 Materials and Methods

3.3.1 Sample Collection and Selection

A total of 135 barley silage samples representing 16 varieties were collected over 2 years (2012-2013) from beef (n = 11), dairy (n = 95) and mixed (n = 29) operations in south-central Saskatchewan and the Lethbridge region of Alberta with the help of feed industry consultants. From this total, 80 samples representing seven varieties were selected for analysis. These included 39 samples from 2012 and 41 from 2013. Selection was based on a minimum of three replicates per variety per year and on the stage of maturity (mid-dough as determined by the producer) at harvest (Table 3.1). Selected varieties included Conlon which is a smooth awned 2 row feed and malting type barley; CDC Copeland and AC Metcalfe which are 2 row malting barley varieties with rough awns; CDC Cowboy and Xena, both 2 row feed barley varieties with rough awns; and Falcon and Legacy which are 6 row varieties with smooth awns.

From the majority of sites, samples were collected using a drill driven silage sampler (Star quality samplers Inc., Irricana, AB) with 2.86 cm diameter cutting tip attached to a 150 cm long probe. Samples were collected from a minimum of four to nine spots from each silo, composited and vacuum packed in duplicate. Of these, one was sent to Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) for chemical analysis and the others frozen at -20°C until processing at a later stage. For processing, frozen samples were thawed overnight at 4°C and a subsample was used for measurement of pH, volatile fatty acids (VFA), lactate, succinate and ammonia concentrations. The remaining sample was dried and analyzed for 6 and 30 h *in vitro* incubation (Daisy^{II} system; Damiran et al., 2008) and indigestible NDF by 288 h of ruminal incubation (Huhtanen et al., 1994). Agronomic data collected included cultivar, seeding and harvest date and stage of maturity at harvest.

Table 3. 1. Barley silage varieties and number of samples used for chemical analysis, *in vitro* incubation (Daisy^{II} system) and INDF

Variety[a]	No. of samples	
	2012	2013
Conlon	5	5
CDC Copeland	6	5
CDC Cowboy	5	3
Falcon	3	3
Legacy	3	9
AC Metcalfe	8	7
Xena	9	9
Total	39	41

Daisy^{II} system is filter bag technique for *in vitro* incubation (Damiran et al., 2008).

[b]Indigestible NDF (INDF) determined by ruminal incubation of samples for 288 h.

[a]Varieties selected based on replicate samples for each year and mid-dough maturity at harvest.

3.3.2 Silage Processing for Volatile Fatty Acids, Lactate, Succinate and Ammonia Concentration

Silage samples were processed for analysis of pH, VFA, lactate and ammonia as described by Zahiroddini et al. (2004) and Addah et al. (2012b). Briefly, fresh silage samples (15 g) were combined with 135 mL double distilled water and blended at 18 000 rpm for 30 s in a commercial blender (Oster® 12 speed blender, Sunbeam Corporation Ltd., Brampton, ON). The suspension was filtered through two layers of cheese cloth and the pH was measured immediately in duplicate using an Accumet Research AR 50 dual channel pH meter (Fisher Scientific, Waltham, MA). Subsequently, 40 mL of the extract was transferred to a 50 mL centrifuge tube (VWR International, Radnor, PA) and stored on ice until centrifuged at 12 000 × *g* for 15 min at 4°C using Beckman Coulter Avanti® J-E centrifuge (Beckman Coulter Inc., Brea, CA). The supernatant (5 mL) was transferred to a 15 mL centrifuge tube (VWR International, Radnor, PA) containing 1 mL of 25% metaphosphoric acid and was used for the analysis of VFA, lactate and succinate. For ammonia analysis, 1.6 mL of the supernatant was transferred to a 2 mL tube with a screw cap top and 'O' ring containing 150 µL of 65% trichloroacetic acid (Addah et al., 2012b). Samples were frozen at -20°C until analyzed.

3.3.3 *In Vitro* Incubation (Daisy^{II} system)

The Daisy^{II} incubation technique (Ankom Technology Corporation, Fairport, NY) was used to estimate *in vitro* ruminal organic matter and NDFD (Wilman and Adesogan 2000; Damiran et al. 2008). Samples were weighed (0.5 g) in acetone rinsed Ankom F57 filter bags (5.0 × 5.5 cm., Ankom Technology Corporation, Fairport, NY), heat sealed and stored until incubation. Both 6 and 30 h incubations consisted of two runs with four replicates of each sample per run. Four Daisy^{II} incubators were used for each run, each with four glass fermentation jars placed on

rotating racks within the cabinet. Each jar had a plastic separation panel with holes and lids with gas relief valves. Each Daisy^{II} incubator contained all 80 samples of the 7 varieties, with incubators maintained at 39.5ºC. Each jar contained 20 randomly allocated samples, two standards (AAFCO standard 1090; average NDF content of 39.6% DM) and two blanks. Ruminal fluid was collected from three ruminally cannulated beef heifers fed a 25:75 concentrate:roughage (DM basis) diet for *ad libitum* intake. Buffer solution (1600 ml) and ruminal fluid (400 ml) were added to each jar, purged with CO_2 and placed into the incubators. At the end of incubation, the jars were drained and the filter bags were rinsed with cold water until the rinse water was clear. After rinsing, the bags were placed in an Ankom^{200} fiber analyzer for determining NDF.

3.3.4 Indigestible NDF

Eight ruminally cannulated beef heifers (452 ± 10 kg; Mean ± SD) were used for the determination of INDF by the *in situ* method. Heifers were housed in one of the pens of the Beef Cattle Research and Teaching Unit at the University of Saskatchewan. During the trial, cattle were fed a diet consisting of 50% barley silage, 45% barley grain and 5% supplement (% DM) for *ad libitum* intake (5 to 10% refusal), with feed delivery at 0800. Diets were formulated to meet or exceed the NRC (2000) requirement for CP, energy, minerals and fat soluble vitamins. All heifers were cared for as per the guidelines of Canadian Council on Animal Care (CCAC 2009).

For each sample, 3 g was weighed in triplicate into 5 × 10 cm size custom made *in situ* bags (6 µm pore size, part no. 07 – 6/5, Sefar America Inc., Depew, NY). In total there were 240 bags (80 samples from 2011 and 2012 all weighed in triplicate). Bags were assigned randomly to each heifer. Sample bags were placed in a laundry bag with a weight to keep the samples immersed and

placed in the ventral sac of the rumen and incubated for 288 h (Huhtanen et al., 1994). Total number of bags incubated in the rumen did not exceed 30 per animal.

After incubation, the bags were removed from the rumen and rinsed in cold water until the rinse water was clear. After rinsing, the bags were soaked in cold water for 30 min. Bags were then dried at 55ºC for 48 h. After drying, the weight of the bag with residue was recorded.

3.3.5 Chemical Analysis

All silage samples were dried in a forced-air oven at 55ºC for 72 h. After drying, the samples were ground through a 1-mm screen (Christy & Norris 20 cm arm Lab mill, Christy Turner Ltd. Chelmsford, UK). Detailed chemical and nutrient analysis of silage samples were done at Cumberland Valley Analytical Services (CVAS; Hagerstown, MD). Samples were analyzed for DM by drying at 135ºC (method 930.15; AOAC 2000), CP (method 990. 03; AOAC 2000) using a Leco FP 528 Nitrogen Combustion Analyzer (Leco, St Joseph, MI), soluble protein by the borate-phosphate procedure (Krishnamoorthy et al. 1982), acid detergent insoluble crude protein (method 990.03; AOAC 2000), neutral detergent insoluble crude protein (method 990.03; AOAC 2000), rumen degradable protein by the procedure outlined by Krishnamoorthy et al. (1983), ADF (method 973.18; AOAC 2000) and NDF by the method of Van Soest et al. (1991) with the addition of amylase and sodium sulfite. The NDF residues after ruminal incubation for NDFD and INDF were also analyzed using the same method. Lignin was determined as described by Goering and Van Soest (1970), ethanol soluble carbohydrate by the method of Hall et al. (1999), starch as described by Hall (2009), ash (method 942.05; AOAC 2000), fat using a tecator extraction unit (method 2003.05; AOAC 2000) and minerals including Ca, P, Mg, K, S, Na, Cl, Fe, Mn, Zn and Cu (method 985.01; AOAC 2000).

Samples for VFA were analyzed using a Hewlett Packard model 5890A series plus II gas-liquid chromatograph (Hewlett Packard Co., Palo Alto, CA) with a 30m Zebron free fatty acid phase fused silica capillary, 0.32 mm i.d. and 1µm film thickness column (Phenomenex, Torrance, CA). Crotonic acid was used as an internal standard. Samples for lactic and succinic acid were methylated and then quantified using the method of Kudo et al. (1987) using the same column and chromatograph as for VFA with malonic acid as an internal standard. Concentration of ammonia was determined by the colorimetric method using the phenol-hypochlorite procedure outlined by Broderick and Kang (1980).

3.3.6 Calculations and Statistical Analysis

Non-fiber carbohydrate (NFC) was calculated as NFC, % = 100 – (CP % + Fat % + Ash % + NDF % + NDFICP %; Linn 2003) where NDFICP is neutral detergent fiber insoluble crude protein. Nonstructural carbohydrate content (NSC) was calculated as sum of sugars, starch, organic acids and fructans (NRC 2001). Total digestible nutrient (TDN) was calculated as per Weiss summative equation (Weiss 1998) as TDN = 0.98 × (100 – NDFn – CP – ash – EE) + $e^{0.012 \times ADIN}$ × CP + 2.25 × (EE – 1) + 0.75 × (NDFn – Lignin) × [1 – (Lignin / NDF)$^{0.667}$] – 7 where NDFn = nitrogen free neutral detergent fiber calculated as NDF – NDICP (% DM), NDICP = NDIN × 6.25 and ADIN expressed as a % of total N. Indigestible NDF ($INDF_{288}$) was calculated as $INDF_{288}$ = [NDF_{288} ÷ NDF] ×100 where $INDF_{288}$ is the total indigestible NDF fraction (% NDF); NDF_{288} is the amount of NDF remaining in the bag after 288 h of incubation (g) and NDF is the amount of NDF in the bag before ruminal incubation (g). Digestible NDF (DNDF, %) was calculated as (100 – $INDF_{288}$ %). The NDFD (6 and 30 h; % NDF) was calculated as NDFD (% NDF) = (NDF in feed – NDF in residue after *in vitro* incubation) ÷ NDF in feed. The NDFD (6 and 30 h; % DNDF) was

calculated as NDFD (% DNDF) = (NDF in feed – NDF in residue after *in vitro* incubation) ÷ DNDF in feed.

Chemical composition of selected silage varieties was analyzed as a randomized complete block design (RCBD) with year as a random blocking factor using a mixed model procedure of SAS (version 9.4; SAS Institute, Inc. Cary, NC) and the model:

$Y_{ijk} = \mu + V_i + \beta_j + \varepsilon_{ijk}$

where Y_{ijk} was the observation of the dependent variable, μ is the population mean, V_i was the fixed effect of variety (i = 1 to 7), β_j was the random effect of block (j = 1 to 2) and ε_{ijk} the random error associated with the observation. The Daisy^{II} NDFD data were analyzed as RCBD with year as a random blocking factor using a mixed model procedure of SAS (Version 9.4, SAS Inc. 2013) and the model:

$Y_{ijklm} = \mu + V_i + \beta_j + D_k + R_l + \varepsilon_{ijklm}$

where Y_{ijklm} was the observation of the dependent variable, μ was the population mean, V_i was the fixed effect of variety (i = 1 to 7), β_j was the random effect of block (j = 1 to 2), D_k was the random effect of Daisy^{II} (k = 1 to 4), R_l was the random effect of run (l = 1 to 2) and ε_{ijklm} the random error associated with the observation.

Indigestible NDF data were analyzed as RCBD with year as a random blocking factor using a mixed model procedure of SAS (Version 9.4, SAS Inc. 2013) and the model:

$Y_{ijkl} = \mu + V_i + \beta_j + R_k + \varepsilon_{ijkl}$

where Y_{ijkl} was the observation of the dependent variable, μ was the population mean, V_i was the fixed effect of variety (i = 1 to 7), β_j was the random effect of block (j = 1 to 2), R_k was the random effect of run (k = 1 to 3) and ε_{ijkl} the random error associated with the observation. Denominator degrees of freedom were determined using the Kenward-Roger option. Growing days was used as

a covariate to analyze any potential effect of variation in maturity at harvest on chemical and digestibility parameters. Mean separation was done by Tukey's test. Significant differences and trends were declared at $P \leq 0.05$ and $0.05 < P \leq 0.10$, respectively.

3.4 Results and Discussion

The intent of this study was to carry out a survey of the nutritional quality of barley silage varieties commonly grown by beef and dairy producers. In western Canada, barley silage is commonly harvested at early to mid-dough maturity as this is considered to be optimal from the point of view of balancing DM yield with acceptable nutrient quality (McAllister and Hristov 2000; Kaulbars and King 2004). For this reason, only samples harvested at mid-dough were used for this study. In addition, to determine if variation in maturity at harvest influenced the chemical and digestibility results, the number of growing days was used as a covariate. The analysis of covariance results indicated no significant effects of the covariate and thus it was removed from the model.

Detailed chemical composition of the selected barley varieties is presented in Tables 3.2 through 3.5. The average pH of the silage samples across varieties was 4.05 ± 0.07 (Mean ± SD; Table 3.2), indicating adequate ensiling in all samples. AC Metcalfe had a higher pH ($P < 0.05$) than Xena with other varieties being intermediate and not differing from each other. Acosta et al. (1991) reported that whole crop barley is easily ensiled owing to its low buffering capacity and high fermentable carbohydrate content. This is evident in the results of this study as the mean pH of the samples was within the range of 3.98 to 4.17, which is considered to be a pH range reflective of well-preserved whole crop cereal silages (Jacobs et al. 2009).

Table 3. 2. Composition and forage quality of barley silage varieties collected in 2012 and 2013

	Variety								
Item[b]	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena	SEM[a]	*P* value
pH	4.05*ab*	4.02*ab*	4.11*ab*	3.98*ab*	4.10*ab*	4.17*a*	3.94*b*	0.052	< 0.01
DM	35.5	37.0	36.9	35.0	37.4	38.3	36.2	1.33	0.61
Composition (% DM)									
EE	3.3	3.1	3.0	3.1	2.8	3.1	2.9	0.15	0.28
Ash	7.1*ab*	6.5*b*	7.8*a*	7.8*a*	7.4*ab*	7.4*ab*	6.6*b*	0.31	< 0.01
Ca	0.34*ab*	0.30*ab*	0.37*a*	0.33*ab*	0.39*a*	0.38*a*	0.26*b*	0.023	< 0.01
P	0.30*abc*	0.29*bc*	0.32*ab*	0.34*a*	0.27*bc*	0.30*ab*	0.26*c*	0.022	< 0.01

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

[a]SEM, pooled standard error of mean.

[b]DM, dry matter; EE, ether extract; Ca, calcium; P, phosphorus.

Similarly, the DM of the varieties ranged from 35.0 – 38.3% which is within the range (30.0 to 40.0%) reported to be optimal for ensiling (Baron et al. 1992). There was no effect of variety on EE content, but CDC Cowboy and Falcon silages had higher ash content ($P < 0.05$) relative to CDC Copeland and Xena with other varieties being intermediate. Calcium concentration of CDC Cowboy, Legacy and AC Metcalfe was higher ($P < 0.05$) than Xena. Falcon had the highest P content ($P < 0.05$), while Xena the lowest.

The average CP content across varieties was 11.2 ± 0.9% (Mean ± SD; % DM), ranging from 10.2 to 12.5% (% DM; Table 3.3). Crude protein content of Falcon and AC Metcalfe was higher ($P < 0.05$) than that of CDC Copeland and Xena. Greater CP content of barley varieties like Falcon and AC Metcalfe are of value in feed formulations for high producing dairy cattle and rapidly growing beef cattle that require supplemental CP. For example, early lactation dairy rations are typically formulated for 17.0 to 19.0% CP (Castro et al. 2010; Barlow et al. 2012) while many backgrounding diets for beef cattle are formulated to 12.5 to 13.5% CP (Beliveau and McKinnon 2008; Gibb et al. 2008). Varieties with a higher CP content would help offset protein supplementation costs.

Falcon had a higher soluble protein (SP) content ($P = 0.05$) relative to Legacy. Soluble protein is the fraction of CP that is soluble in borate-phosphate buffer at pH 6.9 while insoluble in tricarboxylic acid (Licitra et al. 1996; Hedqvist and Udén 2006) and consists of non-protein nitrogen (NPN) and some true protein. Average SP content of 63.1 ± 2.8 (Mean ± SD; % CP) across varieties in the present study indicates that silages contain a considerable amount of CP as SP. Ruminal microbes rapidly degrade soluble proteins for microbial protein synthesis.

Table 3. 3. Composition of protein fractions of barley silage varieties collected in 2012 and 2013

	Variety								
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena	SEM[a]	*P* value
Item[b] *(% DM unless otherwise stated)*									
CP	10.9*abc*	10.4*bc*	11.6*abc*	12.5*a*	10.5*abc*	12.2*a*	10.2*c*	0.69	< 0.01
SP	7.1*ab*	6.7*ab*	7.3*ab*	8.1*a*	6.2*b*	7.4*ab*	6.7*ab*	0.42	0.05
SP, %CP	65.3	64.1	62.5	65.1	58.6	60.3	66.0	2.24	0.07
ADICP	0.85	0.85	0.95	0.87	0.86	1.01	0.84	0.101	0.11
ADICP, %CP	7.8	8.3	8.1	7.1	8.0	8.4	8.3	0.53	0.60
NDICP	0.92*b*	0.94*b*	1.07*ab*	1.12*ab*	0.99*ab*	1.21*a*	0.97*b*	0.110	< 0.01
NDICP, % CP	8.4	9.1	9.2	9.1	9.2	9.9	9.4	0.53	0.35
RDP	9.0*ab*	8.5*ab*	9.5*ab*	10.3*a*	8.4*ab*	9.8*ab*	8.4*b*	0.52	< 0.01
RDP, %CP	82.7	82.1	81.3	82.6	79.3	80.2	83.0	1.12	0.08

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

[a]SEM, pooled standard error of mean.

[b]DM, dry matter; CP, crude protein; SP, soluble protein; ADICP, acid detergent insoluble crude protein; NDICP, neutral detergent insoluble crude protein; RDP, rumen degraded protein.

There was no effect of variety on ADICP or ADICP as a % of CP, averaging 0.89 ± 0.07 (Mean ± SD; % DM) and 8.0 ± 0.4 % (Mean ± SD; % CP) respectively, across silage varieties. A review of literature indicated that the ADICP (% CP) of barley silage harvested at mid-dough varied from less than 5% (Zahiroddini et al. 2006; Baah et al. 2011) to over 15% (Zahiroddini et al. 2004; Addah et al. 2012a). The ADICP is the protein fraction contained in the ADF residue which includes protein associated with lignin and tannin, Maillard reaction proteins and other heat damaged proteins (Licitra et al. 1996). This protein fraction is biologically unavailable as it is highly resistant to microbial and mammalian enzymes, consequently providing no metabolizable amino acids to the small intestine (Sniffen et al. 1992). The ADICP is regarded as a good indicator of protein damage due to heating in conserved forages (Acosta et al. 1991). For most feeds, no adjustment in CP is needed when ADICP is less than 10% of CP content of the feed. However, when ADICP as a % of CP exceeds 10%, the CP content of a feed can be increased to account for the unavailable ADICP fraction (Van Soest 1994).

AC Metcalfe had higher ($P < 0.05$) NDICP content relative to Conlon, CDC Copeland and Xena. Neutral detergent insoluble crude protein is the fraction of CP associated with the cell wall that is insoluble in neutral detergent solution. This fraction is slowly degraded in the rumen and the majority escapes to the small intestine depending on passage rate (Sniffen et al. 1992). Mature forages contain considerable amount of NDICP (Hakl et al. 2015). For producers looking to increase both CP and RDP content of the diet, based on these results, AC Metcalfe would be an appropriate variety to grow.

Among the barley varieties analyzed, Falcon had the highest ($P < 0.05$) while Xena the lowest RDP (% DM) content, with all other varieties not differing in this parameter. Rumen degradable protein (RDP) represents the fraction of intake CP that is degraded by ruminal microbes to

ammonia, amino acids or peptides in the rumen. This fraction consists of NPN, amino acids and true protein that are degraded in ruminal fluid (A_1, A_2, B_1, B_2 and B_3 protein fractions; CNCPS) with varying rates of ruminal degradation and passage rates (Tylutki et al. 2008). Ruminal microbes require RDP for microbial protein synthesis. A deficiency in RDP will reduce carbohydrate digestion, microbial yield and result in poor performance whereas excess RDP will result in loss of N as urea. Rumen degradable protein as a % of CP however, did not differ among varieties ($P > 0.05$) and averaged 81.6 ± 1.4 (Mean ± SD; % CP). Similar RDP (% CP) across varieties indicate that microbial protein synthesis from barley protein is likely to vary little among varieties.

The fiber, carbohydrate and energy fractions of the silage varieties are given in Table 3.4. Acid detergent fiber content averaged 27.7 ± 1.6% (Mean ± SD; % DM) across varieties with CDC Cowboy and AC Metcalfe having higher ADF values ($P < 0.05$) than Conlon. Similar to ADF, CDC Cowboy had higher ($P < 0.05$) NDF content than Conlon and Legacy. Average NDF content across the varieties was 44.4 ± 2.7 (Mean ± SD; % DM). The values for ADF and NDF (range of 26.1 to 30.2 and 41.6 to 48.6 % respectively; % DM) were typical for barley silages harvested at mid-dough (Acosta et al. 1991; Khorasani et al. 1997; Addah et al. 2012b). In a recent evaluation of forage type barley varieties for yield and nutritive value in the Peace region of Alberta, Gill et al. (2013) reported a greater ADF (33.0%) and NDF (52.5%) content for CDC Cowboy relative to other 2 row barley varieties.

Table 3. 4. Composition of fiber, carbohydrate and energy fractions of barley silage varieties collected in 2012 and 2013

	Variety								
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena	SEM[a]	*P* value
Item[b] *(% DM unless otherwise stated)*									
ADF	26.1*b*	27.6*ab*	30.2*a*	26.3*ab*	26.7*ab*	29.6*a*	27.7*ab*	1.02	< 0.01
ADF, % NDF	62.3	62.4	62.4	62.2	63.9	62.5	61.8	1.18	0.72
NDF	41.9*c*	44.3*abc*	48.6*a*	42.2*bc*	41.6*c*	47.3*ab*	44.8*abc*	1.21	< 0.01
Lignin	3.82*ab*	3.71*b*	4.40*ab*	3.75*ab*	3.95*ab*	4.46*a*	4.04*ab*	0.294	0.01
Lignin, % NDF	9.14	8.42	9.14	8.89	9.44	9.44	9.00	0.558	0.36
ESC	3.39	4.31	3.24	1.76	3.10	2.42	3.41	0.875	0.17
NFC[c]	37.8*a*	36.7*ab*	30.1*b*	35.6*ab*	38.5*a*	31.2*b*	36.4*a*	1.72	< 0.01
Starch	22.8*a*	21.0*ab*	14.7*b*	22.5*ab*	24.7*a*	18.3*ab*	20.0*ab*	1.73	< 0.01
Starch, % NFC	60.6	57.1	48.5	61.6	63.2	56.6	54.5	3.59	0.12
NSC[d]	26.2*ab*	25.3*abc*	17.9*c*	24.3*abc*	27.8*a*	20.7*bc*	23.4*abc*	1.84	< 0.01
TDN[e]	67.4*a*	67.2*a*	63.6*b*	66.6*ab*	66.2*ab*	64.4*b*	66.2*ab*	1.09	< 0.01

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

[a]SEM, pooled standard error of mean.

[b]ADF, acid detergent fiber; NDF, neutral detergent fiber; ESC, ethanol soluble carbohydrate; NFC, non-fiber carbohydrate; NSC, non-structural carbohydrate; TDN, total digestible nutrients; CVAS, Cumberland Valley Analytical Services.

[c]NFC calculated as NFC, % = 100 – (CP % + Fat % + Ash % +NDF % + NDFICP %); CVAS, Hagerstown, MD.

[d]NSC calculated as NSC, % = sugars % + starch %; CVAS, Hagerstown, MD.

[e]TDN calculated as per Weiss summative equation (Weiss 1998); CVAS, Hagerstown, MD.

Forage NDF content has been reported to be negatively correlated to DMI in beef (Reid et al. 1988) and dairy cattle (Arelovich et al. 2008). Waldo (1986) reported that NDF is the single best chemical predictor of voluntary DMI in ruminants. As well, Galyean and Defoor (2003) reported that dietary NDF accounts for 92% of variation in DMI of steers. Greater dietary NDF content regulates the DMI of cattle fed high forage diets through gut fill as forage NDF is less dense, digested slowly and retained in the rumen longer than other dietary components (Allen 2000; Allen and Bradford 2009). In dairy cattle, it has been reported that depending on forage quality, DMI is negatively affected when NDF intake as a % of BW reaches 1.2 to 1.5% (Mertens 1985; Murphy 2004). Based on these observations, it is likely that DMI of growing cattle fed high NDF barley varieties like CDC cowboy and AC Metcalfe will be impacted to a greater extent relative to those fed low NDF varieties like Conlon, Falcon and Legacy.

Across the silage samples, lignin concentration ranged from 3.7 to 4.5% and averaged 4.0 ± 0.3% (Mean ± SD; % DM). Lignin content of AC Metcalfe was higher ($P < 0.05$) relative to CDC Copeland. Rustas et al. (2011) reported similar lignin values (5.8 ± 3.9, Mean ± SD; % DM) for barley samples ensiled atmid-dough. Moreover, lignin as a % of NDF did not vary ($P > 0.05$) across the varieties and averaged 9.1 ± 1.2 (Table 3.4). Lignin concentration has been reported to be negatively correlated to cell wall digestibility (Jung and Deetz 1993). Cross linking of lignin with cell wall components prevents physical access by hydrolytic microbial enzymes for cell wall degradation (Jung and Deetz 1993).

Legacy had higher ($P < 0.05$) NFC and NSC concentrations than CDC Cowboy. Non fiber carbohydrate (NFC) represent highly digestible cell contents including sugars, starches and pectins, while nonstructural carbohydrates (NSC) include sugars and starches. Both NFC and

NSC are digested faster than most of the cell wall components in the rumen and represent a readily available source of energy for ruminal microbes.

In the current data set, starch content of Legacy was the highest ($P < 0.05$) while CDC Cowboy the lowest. Average starch concentration across the varieties was 20.6 ± 3.3% (Mean ± SD; % DM), ranging from 14.7 to 24.7% (DM). A review of literature indicated that the starch content of barley harvested at mid-dough ranged from 16.6% (Zahiroddini et al. 2006) to 25.5 ± 1.5% (Mean ± SD; % DM; Zahiroddini et al. 2004; Addah et al. 2011, 2012b; Baah et al. 2011). The starch content of barley silage is highly correlated with energy content. This is evident from Table 3.4, where total digestible nutrient content averaged 65.9 ± 1.4% (Mean ± SD; % DM), ranging from 63.6 to 67.4% with Conlon and CDC Copeland having higher ($P < 0.05$) TDN than CDC Cowboy and AC Metcalfe, with other varieties being intermediate. Similar TDN for CDC Cowboy (63.2; % DM) was also reported by Gill et al. (2013). These authors reported a lower TDN, NE_m (1.26 Mcal kg^{-1} DM) and NE_g (1.07 Mcal kg^{-1} DM) for CDC Cowboy relative to other 2 row barley varieties evaluated.

It should be noted that the TDN value of a feed ingredient is calculated directly by a summative approach (Weiss 1998; NRC 2001) and is highly dependent on nutrient composition and digestibility. As digestibility of starch is greater than that of cell wall components (Huhtanen et al. 2006), a greater starch content corresponds to a greater TDN for high starch barley varieties like Conlon, Legacy and Falcon relative to that of low starch barley varieties like CDC Cowboy and AC Metcalfe (Table 3.4).

There was no difference ($P > 0.05$) in the concentration of fermentation products among varieties (Table 3.5). Concentration of lactate (57.4 ± 4.8 g kg^{-1} DM; Mean ± SD) and acetate

Table 3. 5. Fermentation characteristics of barley silage samples collected in 2012 and 2013

Item (g kg^{-1} DM)	Variety							SEM[a]	*P* value
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena		
VFA									
Acetate	18.9	10.7	13.3	16.5	11.1	16.2	16.4	3.01	0.39
Propionate	0.36	0.08	0.22	0.69	0.04	0.34	0.21	0.207	0.49
Butyrate	0.61	0.66	0.62	0.50	0.54	0.64	0.50	0.300	0.66
Isobutyrate	0.05	0.07	0.03	0.20	0.04	0.05	0.08	0.047	0.31
Valerate	0.10	0.09	0.10	0.68	0.06	0.09	0.24	0.173	0.27
Isovalerate	0.06	0.07	0.07	0.36	0.04	0.06	0.13	0.088	0.31
Caproate	0.11	0.11	0.12	0.31	0.08	0.11	0.13	0.048	0.10
Lactate	56.7	66.4	55.0	60.5	52.8	53.0	57.6	6.89	0.44
Lactate:Acetate ratio	3.97*b*	8.13*a*	4.84*ab*	5.02*ab*	5.60*ab*	5.06*ab*	3.90*b*	0.612	< 0.01
Succinate	4.85	3.63	3.07	3.79	4.00	5.07	5.32	0.612	0.06
Ammonia	2.34	2.09	2.18	2.88	1.81	2.43	2.11	0.234	0.14

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.
[a]SEM, pooled standard error of mean.

(14.7 ± 3.1 g kg^{-1} DM; Mean ± SD) were similar to values reported by Addah et al. (2011) and Baah et al. (2011) for barley ensiled at mid-dough. Butyrate concentration of all the samples were within the range for good quality silage (< 2.5 g kg^{-1} DM; Ward and de Ondarza 2008). Lactate to acetate ratio for all silage varieties in the present study was greater than 3:1. This is a good indicator of the efficiency of silage fermentation, as a ratio of 3:1 or greater is ideal for well-preserved silage (Jalč et al. 2009).

Neutral detergent fiber digestibility is a measure of the ruminal digestion coefficient of NDF (Francis 2012). It is estimated from *in vitro* incubations which in the literature have ranged from 24 (Dado and Allen 1996) to 48 h (Vogel et al. 1999; Hoffman et al. 2003). While there is some debate as to the preferred length of incubation, 30 h has been suggested to more accurately reflect the ruminal retention of forage NDF (Hoffman et al. 2003; Oba and Allen 2011). The importance of NDFD lies in the fact that it influences the energy value of a forage and can be used in calculations to provide a more accurate measure of TDN and NE by taking into account the digestibility of NDF and other nutrient components in the calculations (NRC 2001).

In this study, NDFD as a % of NDF after 6 h of incubation ($NDFD_{6h}$, % NDF) ranged from 1.67 to 4.83% (Table 3.6). Legacy and Falcon had higher ($P < 0.05$) $NDFD_{6h}$ followed by AC Metcalfe and CDC Cowboy while CDC Copeland, Conlon and Xena exhibited the lowest $NDFD_{6h}$. Similarly, Legacy had higher $NDFD_{6h}$ as a % of total digestible NDF ($NDFD_{6h}$, % of DNDF) while Falcon and AC Metcalfe had intermediate values and Conlon, CDC Copeland, CDC Cowboy and Xena the lowest. Attachment of fiber digesting ruminal microorganisms to the forage is essential for ruminal fiber digestion (Varga and Kolver 1997). The period of time required for ruminal fiber digestion to initiate (lag time) varies depending on forage type, nature of the microbes and the ruminal environment (McAllister et al., 1994). Van Soest et al. (2005)

Table 3. 6. Neutral detergent fiber digestibility and indigestible NDF content of barley silage varieties collected in 2012 and 2013

	Variety								
	Conlon	CDC Copeland	CDC Cowboy	Falcon	Legacy	AC Metcalfe	Xena	SEM[a]	*P* value
Items[b] *(% NDF unless otherwise stated)*									
$NDFD_{6h}$	1.67*c*	1.58*c*	2.37*bc*	4.32*a*	4.83*a*	3.02*b*	2.06*c*	0.294	< 0.01
$NDFD_{6h}$, % DNDF	3.56*c*	3.83*c*	4.02*c*	8.13*b*	11.25*a*	7.20*b*	4.72*c*	0.735	< 0.01
$NDFD_{30h}$	30.5*bc*	31.1*b*	37.0*a*	31.6*b*	27.6*d*	30.8*b*	28.8*cd*	2.55	< 0.01
$NDFD_{30h}$, % DNDF	58.5*c*	65.8*b*	62.5*bc*	57.5*c*	62.7*bc*	71.1*a*	59.0*c*	4.41	< 0.01
$INDF_{288}$, % DM	22.0*bc*	23.6*abc*	22.4*bc*	19.7*c*	24.6*ab*	27.8*a*	25.3*ab*	2.33	< 0.01
$INDF_{288}$	50.7*abc*	52.8*ab*	41.0*c*	45.1*bc*	55.5*ab*	58.0*a*	51.2*abc*	3.66	< 0.01
DNDF	49.3*abc*	47.2*bc*	59.0*a*	54.9*ab*	44.5*bc*	42.0*c*	48.8*bc*	3.66	< 0.01

Note: Means within a column not sharing a lowercased italic letter differ significantly at the $P < 0.05$ level.

[a]SEM, pooled standard error of mean.

[b]$NDFD_{6h}$ and $NDFD_{30h}$, neutral detergent fiber digestibility as measured after 6 and 30h *in vitro* incubation (Daisy^{II} system) respectively as % of NDF and digestible NDF; $INDF_{288}$, indigestible NDF measured based on 288 h *in situ* incubation; DNDF, potentially digestible NDF.

reported that a 6 h *in situ* incubation of forage is a good estimate of lag time with most forages exhibiting an average lag time of 4 h. The $NDFD_{6h}$ results indicated that the time required for initiation of fiber digestion is less than 6 h for all varieties and that minimal differences exist between the barley varieties in initiation of fiber digestion.

In terms of $NDFD_{30h}$ expressed as a % of NDF, CDC Cowboy had the highest ($P < 0.05$) while Legacy the lowest $NDFD_{30h}$ with the other varieties exhibiting intermediate values (Table 3.6). In contrast, AC Metcalfe had the highest ($P < 0.05$) $NDFD_{30h}$ (% DNDF), while Conlon, Falcon and Xena had the lowest with other varieties intermediate and not different from each other. Greater NDFD of forages has been reported to improve the DMI of cattle (Oba and Allen 1999a) when intake is limited by ruminal fill. Oba and Allen (1999b) reported 0.17 kg increase in DMI and 0.25 kg increase in 4% fat corrected milk with a one-unit increase in NDFD. Similar improvements in DMI could also be expected for beef cattle fed barley silage based backgrounding diets. Barley varieties like CDC Cowboy with a greater $NDFD_{30h}$ are expected to improve the DMI and milk yield in dairy cattle and feedlot performance of beef cattle relative to barley varieties like Legacy and Xena having a lower $NDFD_{30h}$, provided the composition is similar across barley varieties.

Indigestible NDF content is used as an indicator of forage digestibility and used for digestible energy predictions in mechanistic rumen models (Kramer et al. 2012; Krizsan and Huhtanen 2013). Among the barley varieties evaluated in this study, AC Metcalfe had a higher ($P < 0.05$) $INDF_{288}$ (% DM) content than Falcon, CDC Cowboy and Conlon with other varieties being intermediate. When expressed as a % of NDF, AC Metcalfe also had a higher ($P < 0.05$) $INDF_{288}$ (% NDF) content than CDC Cowboy and Falcon (Table 3.6) with other varieties being intermediate and not different from each other. These results indicate that the digestible NDF

pool of CDC Cowboy is higher relative to AC Metcalfe (59% vs 42%) with intermediate values for the other varieties (Table 3.6). This despite the fact that AC Metcalfe and CDC Cowboy had similar NDF contents (47.3 vs 48.6% DM, respectively; Table 3.4). These results highlight the value of approaches to estimate ruminal availability of NDF. For example, while AC Metcalfe had a higher ($P < 0.05$) $NDFD_{30h}$ (%DNDF), CDC Cowboy had a higher $NDFD_{30h}$ (%NDF). However, since the potentially digestible NDF pool for AC Metcalfe is less than that of CDC Cowboy (Table 3.6), the potential contribution of NDF to digestible energy is greater in CDC Cowboy than in AC Metcalfe. Such traits may be valuable selection tools for forage breeders looking to improve varieties from a nutritional perspective.

These differences in *in vitro* NDFD between barley varieties grown for silage also have important implications for cattle producers. As reported by Oba and Allen (1999b) with corn silage and Oba and Swift (2014) with barley silage, feeding high producing dairy cows forages with a higher NDFD improves performance in terms of DMI, milk yield and efficiency of milk production. Although similar studies with beef cattle are lacking, feeding a high NDFD barley silage variety to backgrounding or finishing cattle would have the potential to improve performance though enhanced ruminal fiber digestibility, and increased DM and digestible energy intake. It should be pointed out however, that even though CDC Cowboy had the highest $NDFD_{30h}$, (% NDF), it also had the highest NDF content (48.6, % DM) and the lowest starch content (14.7, % DM). It is not possible to predict from the current data set the degree to which the higher NDFD offsets the lower starch content in terms of overall digestible energy content. Further research is required to determine the implications of these contrasting chemical and digestive characteristics of the barley varieties used in this study on performance parameters of beef and dairy cattle.

3.5 Conclusion

Seven varieties of barley grown in each of two years and harvested at mid-dough by cattle producers in Saskatchewan and Alberta were compared on the basis of nutrient content and NDFD. Variability in CP, ADF, NDF and starch content indicated that the barley varieties tested are inherently different in chemical composition. Crude protein content of AC Metcalfe was greater than that of Xena. CDC Cowboy had the highest ADF and NDF content and lowest starch content. As well, CDC Cowboy ranked higher in terms of $NDFD_{30h}$ (% NDF) followed by Conlon, CDC Copeland, Falcon and AC Metcalfe with Legacy and Xena ranked lower. CDC Cowboy also had the highest potentially digestible NDF pool while AC Metcalfe the lowest. However, silage fermentation parameters including VFA, lactate and ammonia concentrations were similar across the varieties. Results indicate that there is potential for plant breeders to select barley forage varieties for nutritional characteristics that could allow producers to grow barley silage with enhanced nutrient and digestibility parameters.

It should be noted that the barley silage samples evaluated in the present study were collected from varying geographical locations and were harvested at mid-dough as perceived by individual producers. It would be interesting to evaluate the barley varieties ranked high, intermediate and low in terms of $NDFD_{30h}$ in the present study when seeded, treated and harvested similarly and ensiled at mid-dough at the same geographical location. Moreover, backgrounding and finishing feedlot studies and metabolism trials would provide insights into the effect of variety and level of inclusion of barley varieties potentially varying in $NDFD_{30h}$ on performance, carcass characteristics, ruminal fermentation, total tract nutrient digestibility and digestible energy content of the diet.

4.0 Effect of Variety and Level of Inclusion of Barley Varieties for Silage Selected to Vary in NDF Digestibility on Performance and Carcass Characteristics of Growing and Finishing Beef Steers

4.1 Abstract

Three ensiled barley varieties (CDC Cowboy, CDC Copeland and Xena) selected for differences in 30-h NDFD ($NDFD_{30h}$) were fed at 2 (LOW and HIGH) inclusion rates to study their effects on performance of crossbred steers (n = 288) in a 3 × 2 factorial design. Diets with the LOW inclusion level during backgrounding had a 1:1 barley silage to barley grain ratio while HIGH diets had a 2:1 ratio (% DM basis). Respective ratios during finishing were 1:17 and 1:5. Actual $NDFD_{30h}$ averaged 37.6 ± 3.5, 34.7 ± 3.8 and 36.9 ± 3.0% for CDC Cowboy, CDC Copeland and Xena, respectively. Backgrounding diets containing CDC Cowboy as well as the HIGH diets had greater ($P < 0.01$) ADF and NDF content. Steers fed CDC Cowboy as well as the HIGH diets during backgrounding had lower ($P < 0.01$) DMI, ADG and end of backgrounding BW. During finishing, ADG and DMI were greater ($P < 0.01$) for steers fed HIGH barley silage diets. The results indicate that barley variety and inclusion level had the greatest impact during backgrounding and highlight the difficulty in choosing barley varieties for silage based on a single nutritional parameter like $NDFD_{30h}$.

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Key words: barley silage, variety, level, steers, performance

4.2 Introduction

Because of the short growing season in western Canada, whole-crop barley (*Hordeum vulgare* L.) is the major annual cereal source for silage for feedlot operations (McAllister et al. 1995; Juskiw et al. 2000; Addah et al. 2011). However, when selecting the variety of barley to be seeded, cattle producers tend to place more emphasis on agronomic than nutritional characteristics owing to a lack of information on the nutritional value of the common barley varieties grown for silage. Nair et al. (2016) recently showed that barley silage varieties grown commercially and harvested at mid-dough differed in chemical composition and NDF digestibility (NDFD). For example, of the seven barley varieties compared, these authors reported that CDC Cowboy had the greatest NDF and lowest starch content relative to varieties such as Conlon and Legacy. However, CDC Cowboy had the greatest NDFD after 30-h *in vitro* incubation ($NDFD_{30h,}$ % of NDF) followed by varieties like Conlon, CDC Copeland, Falcon and Metcalfe, while Xena and Legacy had the lowest $NDFD_{30h}$. Forages with greater NDFD improve DMI and milk yield of dairy cattle (Oba and Allen 1999; Ballard et al. 2001; Kung et al. 2008). However, the effect of feeding barley forages potentially varying in NDFD on growing and finishing performance has not been extensively studied.

Barley forage varieties with greater *in vitro* NDFD may be successfully substituted for a portion of the barley grain in ruminant diets without compromising production potential of high producing animals (Oba 2013). In addition, barley forages with greater NDFD will allow for a greater inclusion of forage at equal energy density allowing for a reduction in metabolic disorders and possibly feed costs. The objectives of this study were to evaluate the effects of three ensiled barley varieties that were previously shown to vary in $NDFD_{30h}$ at two inclusion levels in beef backgrounding and finishing diets on performance and carcass characteristics.

4.3 Materials and Methods

4.3.1 Agronomic Practices

Seed for CDC Cowboy (Ardell seeds, Vanscoy, SK), CDC Copeland (Wylie Farms Ltd., Biggar, SK) and Xena (Crop Production Services, Bow Island, AB) were sourced commercially. Each variety was seeded in 16 ha of non-irrigated land (52º09'N 106º36'W, 497 m elevation) at the University of Saskatchewan (Saskatoon, SK), with each field separated by a 3 m border. Seed was pre-treated uniformly with a systemic fungicide and seed protectant Rancona® pinnacle (Chemtura Canada Co., Elmira, ON) and seeded at a rate of 120 kg ha $^{-1}$ using an air drill (1830 air hoe drill; John Deere, Moline, IL) with 25-cm row spacing. Fertilizer (granular 46-0-0) was side banded with the seed at 22.5 kg ha $^{-1}$ and 56 kg ha $^{-1}$ with a 5-cm spacing from the seed row. Achieve® Liquid (Dow Agrosciences Canada Inc., Calgary, AB) and OcTTain^{TM} XL (Dow Agrosciences Canada Inc., Calgary, AB) herbicides were applied for post-emergence control of annual and broad-leaf weeds. Two applications of fungicide (Tilt® 250E; Syngenta Canada Inc., Guelph, ON and Bumper 418 EC®; Makhteshim Agan of North America, Inc., Raleigh, NC) were carried out between tillering and pre-heading. All 3 varieties were harvested at mid-dough and ensiled separately in piles without the addition of a silage inoculant. All three silos were opened after 40-d of ensiling. Chemical and nutrient composition of the three barley silages used are presented in Table 4.1. Barley grain, brome grass hay, canola meal and the vitamin-mineral supplement were purchased from commercial sources. Prior to feeding, barley grain was dry-rolled (Roskamp Champion, Waterloo, IA) to a processing index of 78% and bromegrass hay

Table 4. 1. Chemical composition of barley silage varieties used for the feedlot trial

	Variety		
Item (n = 6)	CDC Cowboy	CDC Copeland	Xena
pH	3.91 ± 0.08	4.09 ± 0.11	3.95 ± 0.16
DM	28.8 ± 1.31	30.9 ± 1.66	30.6 ± 0.79
% DM basis unless otherwise stated			
CP	12.5 ± 0.37	12.0 ± 0.37	12.4 ± 0.33
SP	8.88 ± 0.57	8.35 ± 0.30	9.18 ± 0.60
SP, % of CP	70.9 ± 3.25	69.5 ± 1.43	74.0 ± 3.62
ADICP	0.97 ± 0.05	1.03 ± 0.07	0.93 ± 0.06
ADICP, % of CP	7.73 ± 0.47	8.58 ± 0.75	7.52 ± 0.58
NDICP	1.09 ± 0.11	1.10 ± 0.08	1.02 ± 0.07
NDICP, % of CP	8.65 ± 0.90	9.10 ± 0.84	8.25 ± 0.72
EE	3.16 ± 0.17	3.07 ± 0.15	3.27 ± 0.16
ADF	34.0 ± 0.83	32.2 ± 1.25	31.2 ± 0.66
Lignin	4.55 ± 0.16	4.77 ± 0.27	4.40 ± 0.19
Starch	11.2 ± 0.83	14.8 ± 1.41	16.4 ± 0.75
Ash	8.77 ± 0.49	7.96 ± 0.37	7.98 ± 0.11
Ca	0.43 ± 0.02	0.44 ± 0.02	0.38 ± 0.01
P	0.33 ± 0.01	0.31 ± 0.01	0.32 ± 0.01
NE_m, Mcal kg^{-1} DM[a]	1.36 ± 0.03	1.39 ± 0.04	1.43 ± 0.03
NE_g, Mcal kg^{-1} DM[a]	0.78 ± 0.03	0.82 ± 0.03	0.85 ± 0.02
NDF parameters (n = 6)[b]			
NDF	52.9 ± 1.4	49.4 ± 1.4	49.4 ± 1.7
$NDFD6_h$, % of NDF	6.05 ± 2.45	4.36 ± 2.38	4.71 ± 2.22
$NDFD_{30h}$, % of NDF	37.6 ± 3.50	34.7 ± 3.79	36.9 ± 2.96

Note: DM, dry matter; CP, crude protein; SP, soluble protein; ADICP, acid detergent insoluble CP; NDICP, neutral detergent insoluble CP; EE, ether extract; ADF, acid detergent fiber; Ca, calcium; P, phosphorus; NE_m and NE_g, net energy of maintenance and gain calculated from chemical composition.

[a]Net energy for maintenance and gain is calculated by summative energy equation (NRC 2001).

[b]Analyzed by wet chemistry as per the method of Van Soest et al. (1991) for NDF and Damiran et al. (2008) for NDF digestibility as measured after 6 ($NDFD_{6h}$) and 30 h ($NDFD_{30h}$) *in vitro* incubation ($Daisy^{II}$ system) respectively.

was ground through a 9.5-cm screen using a tub grinder (Haybuster H-1000, DuraTech industries International, Jamestown, MD).

4.3.2 Animal Care and Experimental Design

Two hundred and eighty-eight cross-bred steers (320 ± 23.1 kg; Mean ± SD) were purchased from commercial sources and housed at the University of Saskatchewan Beef Cattle Research and Teaching Unit (BCRTU). Upon arrival, the steers were ear tagged and processed as per Zenobi et al. (2014) and implanted with Revalor® -G (Merck animal health, Kirkland, QC). Steers were re-implanted with Ralgro® (Merck animal health, Kirkland, QC) at the beginning of the finishing phase and Revalor® -S (Merck animal health, Kirkland, QC) was used as the terminal implant. Steers were vaccinated for foot rot and liver abscesses with Fusogard® (Novartis animal health US Inc., Larchwood, IA) one month after the beginning of the finishing phase with a booster dose 30 d later. Animals were cared for according to the guidelines of Canadian Council on Animal Care (CCAC; 2009) as per the approved University of Saskatchewan Animal Care Protocol # 19940033.

The experiment was designed as a completely randomized design with a 3 (variety) by 2 (dietary level of inclusion) factorial treatment arrangement. Steers were weighed on 2 consecutive days at the beginning of the trial and the average was used as the start of test weight. Steers were stratified by weight and randomized to one of 24 outdoor pens with 12 head per pen. Each pen was assigned randomly to one of 6 dietary treatments.

4.3.3 Treatments and Dietary Composition

Treatments included three barley silage varieties (CDC Cowboy, CDC Copeland and Xena) fed at two inclusion levels (LOW and HIGH; Table 4.2). HIGH barley silage inclusion levels in

backgrounding and finishing diets were achieved by replacing a portion of barley grain in the LOW inclusion diets with the corresponding variety of barley silage, keeping inclusion of hay, canola meal and supplement constant. The study consisted of a 68 d backgrounding and a 148 d finishing phase. LOW silage inclusion backgrounding diets were formulated to 12.5% CP and 1.62 and 1.01 Mcal kg^{-1} NE_m and NE_g, respectively. (% DM basis; Table 4.2). HIGH silage inclusion diets were formulated to 12.5% CP and 1.55 and 0.95 Mcal kg^{-1} NE_m and NE_g, respectively (% DM basis). Barley silage:barley grain ratio was maintained at 1:1 for the LOW and 2:1 for the HIGH barley silage inclusion diets during backgrounding (% DM basis).

At the end of backgrounding, steers were transitioned to the final finishing diets using a 12-d, 5-step adaptation program, where the diet composition was changed every 3 d in such a way that the barley silage and hay content in the diet were gradually decreased as barley grain was increased to formulated levels in the finishing diet. Canola meal and supplement concentrations were also adjusted to the finishing levels (% DM basis) by the final step of dietary adaptation. LOW silage inclusion finishing diets were formulated to 12.0% CP and 1.87 and 1.23 Mcal kg^{-1} NE_m and NE_g, respectively (% DM basis; Table 4.2). HIGH silage inclusion finishing diets were formulated to 12.0% CP, 1.82 and 1.19 Mcal kg^{-1} NE_m and NE_g, respectively (% DM basis). Barley silage:barley grain ratio during finishing was maintained at 1:17 and 1:5 for LOW and HIGH barley silage inclusion diets, respectively (% DM basis).

Backgrounding and finishing diets were formulated to meet or exceed National Research Council (NRC 2000) nutrient requirements for the targeted level of growth. Calcium to phosphorus (P) ratios were formulated to range from 1.5:1 to 2:1 throughout backgrounding and finishing. Monensin sodium was incorporated in the vitamin-mineral supplement and formulated to

Table 4. 2. Composition of backgrounding and finishing diets used for feedlot trial

	Diets					
	CDC Cowboy		CDC Copeland		Xena	
	LOW	HIGH	LOW	HIGH	LOW	HIGH
Backgrounding diet composition (% DM basis)						
Barley silage	40.1	53.5	40.1	53.5	40.1	53.5
Bromegrass hay	9.4	9.4	9.4	9.4	9.4	9.4
Barley grain	40.1	26.7	40.1	26.8	40.1	26.8
Canola meal	5.6	5.6	5.6	5.6	5.6	5.6
Supplement	4.8	4.8	4.8	4.7	4.8	4.7
Backgrounding supplement composition (% DM basis)						
Ground barley	28.1	28.1	28.1	28.1	28.1	28.1
Ground wheat	25.0	25.0	25.0	25.0	25.0	25.0
Prairie pride pellets[a]	25.0	25.0	25.0	25.0	25.0	25.0
Limestone	15.3	15.3	15.3	15.3	15.3	15.3
Canola oil	1.5	1.5	1.5	1.5	1.5	1.5
Mineral, vitamin premix[b]	5.1	5.1	5.1	5.1	5.1	5.1
Finishing diet composition (% DM basis)						
Barley silage	5.0	15.0	5.0	15.0	5.0	15.0
Barley grain	87.0	77.0	87.0	77.0	87.0	77.0
Canola meal	3.5	3.5	3.5	3.5	3.5	3.5
Supplement	4.5	4.5	4.5	4.5	4.5	4.5
Finishing supplement composition (% DM basis)						
Ground barley	19.9	19.9	19.9	19.9	19.9	19.9
Ground wheat	25.0	25.0	25.0	25.0	25.0	25.0
Prairie pride pellets[a]	25.0	25.0	25.0	25.0	25.0	25.0
Limestone	20.0	20.0	20.0	20.0	20.0	20.0
Canola oil	2.5	2.5	2.5	2.5	2.5	2.5
Mineral, vitamin premix[c]	7.6	7.6	7.6	7.6	7.6	7.6

Note: Barley silage:barley grain ratio for LOW inclusion was 1:1 during backgrounding and 1:17 during finishing. Barley silage:barley grain ratio for HIGH inclusion was 2:1 during backgrounding and 1:5 during finishing.

[a]Contains wheat bran, wheat shorts, wheat middlings, number 1 and 2 feed screenings, barley grain and refuse screenings with guaranteed minimum analysis of 15% crude protein and 3% crude fat and maximum 12.5% crude fiber.

[b]Mineral, vitamin premix for backgrounding diets contained 10.5% CP, 7.0% Ca, 0.38% P, 1.8% Na, 0.24% Mg, 0.66% K, 0.14% S and 5.4 mg Co, 204.2 mg Cu, 18.4 mg I, 111.8 mg Fe, 554.9 mg Mn, 2.2 mg Se, 616.7 mg Zn, and 662.3 mg monensin per kg and 44,150 IU vitamin A, 5,518 IU vitamin D and 662 IU vitamin E per kg supplement.

[c]Mineral, vitamin premix for finishing diets contained 9.6% CP, 10.1% Ca, 0.35% P, 1.8% Na, 0.31% Mg, 0.63% K, 0.13% S and 5.3 mg Co, 202.4 mg Cu, 18.2 mg I, 138.4 mg Fe, 543.8 mg Mn, 2.2 mg Se, 610.8 mg Zn, and 656.5 mg monensin per kg and 43,764 IU vitamin A, 5,470 IU vitamin D and 656 IU vitamin E per kg supplement.

provide 33 mg kg $^{-1}$ diet DM. Dietary NE_m content (Mcal kg $^{-1}$ DM) of both backgrounding and finishing phases were calculated based on animal performance and DMI by a quadratic equation using the retained energy formula for large frame steers [$RE = (0.0493 \times BW^{0.75}) \times ADG^{1.097}$; NRC 1996] as per Zinn and Shen (1998) and Zinn et al. (2002). Net energy of gain was calculated from NE_m assuming $NE_g = NE_m \times 0.877 - 0.41$ as per Zinn and Shen (1998). The targeted end point of backgrounding was 385 kg (shrunk basis) and 625 kg for finishing. At the end of finishing, steers were sent as a single group for slaughter at Cargill Foods, High River, AB.

4.3.4 Data Collection and Analytical Procedures

Feed was delivered to each pen using a feed mixer equipped with a digital scale (Farm Aid Equipment Inc., Model 430, Corsica, SD). Steers were fed once daily starting at 0800 for *ad libitum* intake with a target of 5% feed refusal. Bunks were read each morning and the daily feed allotted was based on the residual feed in the bunk prior to feeding and the amount fed the previous day. Once every 2 wk before feeding, the bunks were cleaned and weights of orts were recorded, sampled and the remainder discarded. Steers were weighed individually before feeding on 2 consecutive days at the start and end of backgrounding and finishing phases to determine initial and final weights. Steers were also weighed every 2 wk throughout the feeding period prior to the morning feeding. Performance parameters (DMI, ADG and G:F) were calculated based on shrunk BW (live BW × 0.96%). Bunk samples of TMR were collected every 2 wk from each pen and composited on a treatment basis. Samples of barley silage and hay were collected every wk and DM was determined to adjust daily feeding amounts as necessary. Ort DM content was used to correct the DMI on a pen basis for each 2 wk period. Barley grain samples were collected before and after rolling as batch samples for determining the processing index. All

samples of feed and TMR were composited on a monthly basis and a representative sample was saved for chemical analysis.

4.3.5 Chemical and NIR Analysis

Samples of orts, TMR and hay were dried in a forced-air oven at 55ºC for 48 h, whereas silage samples were dried for 72 h. After drying, silage and TMR samples were ground through a 1 mm screen (Christy & Norris mill 8" Lab mill, Christy Turner Ltd, Chemsford, UK). Silage samples were analyzed by Near Infrared Reflectance spectroscopy (NIR) at Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) with the exception of NDF which was analyzed by wet chemistry. Samples of TMR were analyzed at CVAS in duplicate for DM at 135ºC [method 930.15; Association of Official Analytical Chemists (AOAC) 2000], CP (method 990.03; AOAC 2000) using a Leco FP 528 Nitrogen Combustion Analyzer (Leco, St. Joseph, MI), EE using a tecator extraction unit (method 2003.05; AOAC 2000), ADF (method 973.18; AOAC 2000), ash (method 942.05; AOAC 2000) and Ca and P (method 985.01, AOAC 2000). The method of Van Soest et al. (1991) with the addition of amylase and sodium sulfite was used to determine NDF content. For measuring silage pH, fresh silage samples (15 g) were combined with 135-mL double distilled water and blended at 18 000 rpm for 30 s in a commercial blender (Oster® 12 speed blender, Sunbeam Corporation Ltd., Brampton, ON). The suspension was filtered through two layers of cheese cloth and the pH was measured immediately in duplicate using an Accumet Research AR 50 dual channel pH meter (Fisher Scientific, Waltham, MA). The $NDFD_{6h}$ and $NDFD_{30h}$ was measured via *in vitro* incubation ($Daisy^{II}$ system) as described by Damiran et al. (2008).

4.3.6 Carcass Traits

Steers were slaughtered at a commercial processing plant (Cargill Foods, High River, AB) at an average BW of 626 ± 45 kg (Mean ± SD; shrunk basis) at the end of the 148 d finishing period. Hot carcass weight was determined immediately and the carcasses were chilled for 24 h and evaluated using the Computer Vision Grading System (VBG 2000 e + v Technology GmbH, Oranienburg, Germany) for grading and marbling score according to Canadian Beef Grading Agency (CBGA 2009). The yield grade (YG) is a measure of the overall lean yield calculated from the rib-eye area and fat depth and consists of Canada 1 = 59% or more; Canada 2 = 58 to 54% and Canada 3 = 53% or less. Marbling scores were: B = devoid; A = trace, AA = slight; AAA = small to moderate; and prime = slightly abundant or greater (CBGA 2009).

4.3.7 Statistical Analysis

Three steers died during the study for reasons not related to diet and hence their data was removed from the analysis. The mixed model procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC) was used to analyze the feedlot performance data with pen as the experimental unit and treatment as a fixed effect. Data were analyzed separately for the backgrounding, finishing and for the overall feeding phases. As the experiment was completely randomized with a 3 × 2 factorial arrangement of treatments, effect of variety (V), level of inclusion (L) and variety × level interaction (V × L) was included in the model. Denominator degrees of freedom were determined using the Kenward-Roger option. Yield and quality grade data were analyzed using GLIMMIX (SAS, version 9.4; SAS Institute Inc., Cary, NC) with binomial error structure and logit data transformation. Significant differences and trends were declared at $P < 0.05$ and $0.10 > P > 0.05$, respectively.

4.4 Results and Discussion

4.4.1 Ingredient and Chemical Profile of the Silage and Total Mixed Ration

The barley varieties evaluated were selected based on the results of Nair et al. (2016) where barley silage samples representing seven varieties from beef and dairy operations in south-central Saskatchewan and Lethbridge region of Alberta were evaluated for chemical and nutritional characteristics. CDC Cowboy, CDC Copeland and Xena were selected for ranking high (37.0%), intermediate (31.1%) and low (28.8%), respectively in terms of $NDFD_{30h}$ (% NDF basis) by *in vitro* incubation ($Daisy^{II}$ system) and for having similar agronomic characteristics. All three varieties were two rowed and hulled with CDC Cowboy considered to be both a grain and silage variety, CDC Copeland a malting and Xena a feed type barley. Both CDC Cowboy and CDC Copeland are rough-awned, whereas Xena is semi-smooth-awned.

Chemical characteristics of barley silage varieties are presented in Table 4.1. As there was only one silage pile per variety, no statistical analysis was carried out and hence means ± SD of samples (n = 6) collected across the feeding period are presented. Silage pH averaged 3.98 ± 0.14 (Mean ± SD) across the varieties. The range in pH is indicative of well-preserved silage (Jacobs et al. 2009; Nair et al. 2016). Whole crop barley is known for easy ensiling (Acosta et al. 1991) due to its low buffering capacity and high water soluble carbohydrate content. Nutrient composition of the silage varieties including concentration of CP, ADF and NDF in the present study was somewhat greater than that reported by Nair et al. (2016). Ether extract content averaged 2.6 ± 0.4 across varieties. Starch content was markedly lower for CDC Cowboy (11.2 ± 0.83 vs. 16.4 ± 0.75) relative to Xena, while CDC Copeland was intermediate. Nair et al. (2016) also reported lower ($P < 0.01$) starch content for CDC Cowboy (14.7%) relative to CDC

Copeland (21.0%) and Xena (20.0%). However, the lower starch content (11.2 vs. 14.7%) for CDC Cowboy in the present study relative to that reported by Nair et al. (2016) likely indicates that this variety was harvested at a slightly early maturity than the targeted mid-dough stage. Relatively greater ADF and NDF content together with lower starch content of CDC Cowboy is reflected by the lower NE_m and NE_g content based on chemical analysis relative to CDC Copeland with Xena being intermediate. Nutrient composition and digestibility greatly affects the TDN and net energy values of forages. Barley varieties like CDC Cowboy with higher cell wall fractions and lower starch content relative to varieties like CDC Copeland and Xena have lower TDN content as digestibility of cell wall fractions is lower than that of cell solubles or storage carbohydrates. Calcium and P content averaged 0.43 ± 0.03 and 0.36 ± 0.03% across the varieties.

CDC Cowboy had numerically greater $NDFD_{6h}$ (6.05 ± 2.45 vs. 4.36 ± 2.38) and $NDFD_{30h}$ (37.6 ± 3.50 vs. 34.7 ± 3.79) relative to CDC Copeland, while Xena was intermediate (Table 4.1). As indicated by the standard deviation, these NDF disappearance values exhibit considerable overlap between the three varieties. These results differ somewhat from those reported by Nair et al. (2016) in a survey on nutritional and NDFD traits of common barley varieties grown commercially for silage in western Canada. These authors reported similar $NDFD_{6h}$ for the three barley varieties used in the present study, while CDC Cowboy had significantly greater $NDFD_{30h}$ relative to Xena, with CDC Copeland being intermediate. Even though $NDFD_{30h}$ of CDC Cowboy in the present study was comparable (37.6 vs. 37.0%) to that reported by Nair et al. (2016), both CDC Copeland (34.7 vs. 31.1%) and Xena (36.9 vs. 28.8%) exhibited greater $NDFD_{30h}$ than previously reported (Nair et al. 2016). The reasons for this variability are not clear, however, it should be noted that environmental conditions including

temperature and precipitation and soil fertility greatly affect forage yield and quality (May et al. 2007). For example, these authors reported greater DM yields for barley grown under conditions of higher precipitation and lower growing degree days. In an evaluation of forage quality of barley varieties, Baron et al. (2000) reported an NDF content of 44.5, 52.5 and 48.3% for the variety Tukwa over three crop years. Similarly, Gill et al. (2013) reported a significant year effect for CP (8.2 to 11.8%), ADF (25.5 to 37.2%), NDF (41.8 to 59.7%) and NE_g content (0.74 to 1.01 Mcal kg^{-1}) across 12 barley varieties grown over three crop years. Chow et al. (2008) reported a greater 30-h *in vitro* NDF digestibility (61.2 vs. 51.9%) for barley seeded early as compared to late in the growing season due to a lower daily mean temperature (14.3 vs. 15.9°C) from heading to harvest. The lack of clear differences in NDFD noted between the three barley varieties in the present study relative to what was reported by Nair et al. (2016) could reflect the environmental growing conditions for barley forages in the crop years 2012 and 2013, where samples were collected from across Saskatchewan and Alberta vs the samples from this study which were collected from one location in the 2014 crop year. These results indicate the difficulty in choosing barley forage varieties for silage based on a single nutrient parameter like $NDFD_{30h}$ when environmental conditions can influence plant growth and nutrient composition.

The ingredient and chemical composition of the backgrounding and finishing diets are presented in Table 4.2 and 4.3. The CP content in the backgrounding diets averaged 12.2 ± 0.48% (Mean ± SD; % DM basis) across varieties (Table 4.3). However, as CDC Cowboy had a greater ADF and NDF content and lower NE_m and NE_g content relative to CDC Copeland and Xena (Table 4.1), composition of TMR showed a variety effect with diets containing CDC Cowboy having a greater ($P < 0.01$) ADF and NDF content and lower NE_m and NE_g content,

Table 4. 3. Nutrient composition of backgrounding and finishing diets used for feedlot trial

	Variety			Level			*P* value		
	CDC Cowboy	CDC Copeland	Xena	LOW	HIGH	SEM	V	L	V × L
Nutrient composition of backgrounding diets (n = 3; % DM basis)									
CP	12.3	12.2	12.3	12.1	12.4	0.21	0.83	0.28	0.75
ADF	26.7*a*	23.0*b*	22.9*b*	22.6*b*	25.8*a*	0.41	< 0.01	< 0.01	0.06
NDF	41.8*a*	36.6*b*	36.5*b*	36.5*b*	40.1*a*	0.56	< 0.01	< 0.01	0.09
Ca	0.66	0.65	0.66	0.60*b*	0.70*a*	0.026	0.94	0.01	0.85
P	0.39*ab*	0.37*b*	0.40*a*	0.39	0.39	0.005	< 0.01	0.74	0.89
NE_m (Mcal kg^{-1} DM)[a]	1.52*b*	1.62*a*	1.65*a*	1.63*a*	1.56*b*	0.011	< 0.01	< 0.01	0.17
NE_g (Mcal kg^{-1} DM)[a]	0.92*b*	1.02*a*	1.04*a*	1.02*a*	0.97*b*	0.010	< 0.01	< 0.01	0.08
Nutrient composition of finishing diets (n = 5; % DM basis)									
CP	11.9	11.9	11.9	12.0	11.9	0.19	0.99	0.77	0.62
ADF	9.9	9.5	9.3	8.3*b*	10.8*a*	0.27	0.31	< 0.01	0.59
NDF	20.9	20.3	19.8	19.1*b*	21.5*a*	0.41	0.25	< 0.01	0.87
Ca	0.56	0.56	0.58	0.54	0.59	0.019	0.85	0.09	0.53
P	0.42	0.41	0.41	0.42	0.40	0.012	0.87	0.42	0.99
NE_m (Mcal kg^{-1} DM)[a]	1.81	1.82	1.84	1.85*a*	1.79*b*	0.012	0.35	< 0.01	0.83
NE_g (Mcal kg^{-1} DM)[a]	1.18	1.19	1.21	1.22*a*	1.17*b*	0.011	0.44	< 0.01	0.86

Note: Barley silage:barley grain ratio for LOW inclusion was 1:1 during backgrounding and 1:17 during finishing. Barley silage:barley grain ratio for HIGH inclusion was 2:1 during backgrounding and 1:5 during finishing. V, variety; L, level of inclusion; V × L, interaction between variety × level of inclusion; SEM, pooled standard error of mean. CP, crude protein; EE, ether extract; ADF, acid detergent fiber; NDF, neutral detergent fiber; Ca, calcium; P, phosphorus. Means within a row not sharing a lower cased letter differ significantly at the P < 0.05 level.

[a]Net energy for maintenance and gain is calculated by summative energy equation (NRC 2001).

relative to those containing CDC Copeland or Xena. Similarly, as expected diets showed a significant forage level effect with lower ADF, NDF and Ca content and greater NE_m and NE_g content ($P \leq 0.01$) for LOW relative to HIGH inclusion diets. These changes reflect the change in dietary composition brought about by replacing barley grain with barley silage as barley grain has a lower ADF (5.8 vs. 33.55%), NDF (18.1 vs. 51.0%) and Ca (0.05 vs. 0.43%) content compared to barley silage (NRC 2000).

There was no variety effect on any of the measured nutrient composition parameters during finishing (Table 4.3). The CP content in the finishing diets averaged 11.9 ± 0.10% (Mean ± SD; % DM basis) and as in backgrounding diets, HIGH silage inclusion diets had a greater ($P < 0.01$) ADF and NDF content and lower NE_m and NE_g content relative to LOW inclusion diets. Calcium and P content averaged 0.57 ± 0.07 and 0.41 ± 0.04% (Mean ± SD; % DM basis) respectively, across treatments.

4.4.2 Animal Performance

Feedlot performance and carcass data are presented in Tables 4.4 through 4.7. As there were no interactions ($P > 0.05$) between barley variety and level of inclusion in the diet for any of the measured performance or carcass characteristics, only main effects are reported.

Barley variety had an effect on performance of steers during backgrounding with cattle fed CDC Cowboy having a lower ($P < 0.01$) EBWT and ADG relative to steers fed CDC Copeland and Xena (Table 4.4). The poorer performance of steers fed CDC Cowboy was likely a result of two factors. First, DMI both in terms of kg d^{-1} (7.7 vs. 8.3 kg d^{-1}) and as a % of BW (2.22 vs. 2.37%) was reduced for steers fed CDC Cowboy vs. those fed CDC Copeland, with

Table 4. 4. Effect of silage barley varieties and their inclusion level in diet on performance of steers over 68-d backgrounding period

	Variety			Level			*P* value		
Item	CDC Cowboy	CDC Copeland	Xena	LOW	HIGH	SEM	V	L	V × L
Initial shrunk BW[a] (kg)	307.3	307.0	306.8	307.1	307.0	0.23	0.51	0.64	0.27
Final shrunk BW[a] (kg)	385.0*b*	391.9*a*	394.1*a*	395.8*a*	384.9*b*	1.49	< 0.01	< 0.01	0.45
ADG (kg)	1.14*b*	1.25*a*	1.28*a*	1.30*a*	1.14*b*	0.023	< 0.01	< 0.01	0.44
DMI (kg d^{-1})	7.68*b*	8.29*a*	8.03*ab*	8.29*a*	7.71*b*	0.110	< 0.01	< 0.01	0.17
DMI (% of BW)	2.22*b*	2.37*a*	2.29*ab*	2.36*a*	2.23*b*	0.029	0.01	< 0.01	0.17
NDF intake (kg d^{-1})	3.21a	3.04ab	2.93b	2.92b	3.20a	0.045	< 0.01	< 0.01	0.11
NDF intake (% of BW)	0.93a	0.87b	0.84b	0.83b	0.93a	0.012	< 0.01	< 0.01	0.08
G:F[b]	0.149*b*	0.151*ab*	0.159*a*	0.157*a*	0.148*b*	0.0041	0.05	0.02	0.65
NE_m[c] (Mcal kg^{-1} DM)	1.74	1.72	1.78	1.76	1.73	0.019	0.10	0.31	0.57
NE_g[c] (Mcal kg^{-1} DM)	1.11	1.09	1.15	1.13	1.11	0.017	0.09	0.33	0.51
NE_g[c] intake (Mcal d^{-1})	8.55b	9.05a	9.24a	9.36a	8.54b	0.123	< 0.01	< 0.01	0.53

Note: Barley silage:barley grain ratio for LOW inclusion was 1:1 and 2:1 for HIGH inclusion. V, variety; L, level of inclusion; V × L, interaction between variety x level of inclusion; SEM, pooled standard error of mean. ADG, average daily gain; DMI, dry matter intake; G:F, gain:feed; NE_m and NE_g, net energy of maintenance and gain. Means within a row not sharing a lower cased letter differ significantly at the $P < 0.05$ level.

[a]Shrunken BW calculated as 96% of live weight (NRC, 1996).

[b]G:F is calculated as ADG/DMI.

[c]Calculated based on performance (Zinn and Shen 1998; Zinn et al. 2002).

Xena being intermediate. Similar results are also reported by Tjardes et al., (2002) using corn hybrids (normal vs male-sterile; 38.6 vs 56.7% NDF) who reported a lower ($P < 0.01$) DMI (kg d^{-1}) for steers fed high NDF silage. A review of the literature indicates significant negative correlation between NDF content of the diet and DMI in beef (Reid et al. 1988) and dairy cattle (Dado and Allen 1996; Oba and Allen 1999; Arelovich et al. 2008). According to Mertens (1996, 2010) and Allen (2000), dietary NDF regulates the DMI in cattle fed high forage diets through gut fill. Forage NDF is less dense, digested slowly and retained in the rumen longer than other dietary components (Allen and Bradford 2009). Waldo (1986) reported that NDF is the single best chemical predictor of voluntary DMI in ruminants. Similarly, Galyean and Defoor (2003) reported that dietary NDF content accounts for 92% of variation in DMI of steers. It is likely that the reduced DMI of steers fed CDC Cowboy is in part a result of greater NDF content of the diets containing this variety (41.8 vs. 36.6%; Table 4.3). This is also evident from the fact that total NDF intake calculated as % of BW was 0.93% ($P < 0.01$) for steers fed CDC Cowboy relative to 0.87 and 0.84% for those fed CDC Copeland and Xena, respectively (Table 4.4). It is not known at what point NDF intake as a % of BW will negatively influence the DMI of growing beef cattle. However, depending on forage quality, in dairy cattle it has been shown that DMI is negatively affected when NDF intake as % of BW reaches 1.2 (Mertens 1985) to 1.5% (Murphy 2004). Due to differences in rumen size, DMI and passage rate, the value where NDF intake as a % of BW impacts DMI in growing beef cattle is likely lower than that of dairy cattle.

Oba and Allen (1999) reported greater DMI in dairy cattle fed high NDFD forages. Forages with greater NDFD break down more rapidly in the rumen during fermentation, increasing passage rate and DMI (Oba and Allen 1999). However, as stated previously, $NDFD_{30h}$

in the present study was numerically similar across barley varieties (Table 4.1) and as such likely had minimum influence on DMI during the backgrounding phase.

The second likely reason for the poorer backgrounding performance of steers fed CDC Cowboy was that they had 0.50 Mcal lower (8.55 vs. 9.05 Mcal d^{-1}; $P < 0.01$) NE_g intake relative to steers fed CDC Copeland and 0.69 Mcal lower NE_g intake (8.55 vs. 9.24 Mcal d^{-1}; $P < 0.01$) compared to those fed Xena (Table 4.4). With cattle of an equal age, frame size and weight, a lower NE_g intake should correspond to poorer backgrounding performance as evidenced by the lower ($P < 0.01$) EBW and ADG for steers fed CDC Cowboy (385.0 kg, 1.14 kg d^{-1}) vs. those fed CDC Copeland (391.9 kg, 1.25 kg d^{-1}) and Xena (394.1 kg, 1.28 kg d^{-1}).

Steers fed CDC Cowboy had poorer ($P = 0.05$) feed efficiency (G:F) relative to those fed Xena with CDC Copeland being intermediate. While not significant, there was a tendency for diets containing Xena to have a greater NE_m ($P = 0.10$) and NE_g ($P = 0.09$) content as estimated from growth rates. This finding is consistent with the improved G:F and greater EBWT of steers fed Xena relative to those fed CDC Cowboy. Similar results were also reported by Nair et al. (2015) where steers fed backgrounding diets with greater NE_g content as estimated from BW, DMI and ADG had greater end trial BW and G:F. It should also be noted that increased energy content of diets containing Xena as estimated by chemical analysis (Table 4.3) was confirmed by energy content determined by growth performance as reported in Table 4.4.

As indicated in Table 4.4, there was also an effect of forage:concentrate (F:C) ratio on backgrounding performance. Steers fed HIGH silage diets during backgrounding exhibited lower ($P \leq 0.02$) DMI expressed as kg d^{-1} (7.7 vs. 8.3 kg d^{-1}) and as a % of BW (2.23 vs. 2.36%), ADG (1.14 vs. 1.30 kg) and G:F (0.148 vs. 0.157) relative to those fed the LOW silage diets. Poorer

performance of steers fed higher F:C ratio was also reported by Hironaka et al. (1994) where steers fed 75:25 F:C ratio had lower ADG (1.04 vs. 1.51 kg), DMI (9.5 vs. 10.3 kg d^{-1}) and G:F (0.110 vs. 0.145) relative to those fed a 58:42 F:C diet. Reduced DMI of steers fed HIGH forage diets in the present study is somewhat unexpected as DMI should increase in order to compensate for a lower dietary energy concentration (Galyean and Defoor 2003) when gut fill is not limiting intake. However, as with steers fed CDC Cowboy, the DMI of steers fed the HIGH forage diets could have been limited by NDF content of the diet (40.1 vs. 36.5%; $P < 0.01$). This is evident from the fact that dietary NDF intake as a % of BW for steers fed HIGH silage diets was greater (0.93 vs. 0.83%; $P < 0.01$) relative to LOW inclusion diets (Table 4.4). Moreover, the greater NDF intake of steers fed HIGH forage diets could have resulted in higher ruminal NDF concentration and retention of fiber resulting in lower DMI relative to steers fed LOW silage diets (Hironaka et al. 1994; Tjardes et al. 2002).

Steers fed HIGH silage diets had 0.82 Mcal lower ($P < 0.01$) daily NE_g intake relative to steers fed LOW silage diets (Table 4.4). This was a result of both reduced DMI (7.7 vs. 8.3 kg; Table 4.4) as well as a lower dietary energy concentration (0.97 vs. 1.02 Mcal NE_g; Table 4.3). Lower NE_g intake will result in reduced performance due to lower accretion of body tissue (NRC 2000). Dietary NE_g content as calculated from BW, DMI and ADG (Table 4.4) was not affected (1.11 vs. 1.13 Mcal kg^{-1}; $P > 0.05$) by the F:C ratio, values which were only slightly higher than formulated levels (Table 4.3).

Effect of silage barley variety and inclusion level in the diet on finishing performance is presented in Table 4.5. Silage barley variety did not ($P > 0.05$) impact any of the measured finishing parameters. There was also no effect of level of silage inclusion on final shrunk BW (average 626 ± 45 kg, Mean ± SD) indicating that steers fed the HIGH silage diets during

Table 4. 5. Effect of silage barley varieties and their inclusion level in diet on performance of steers over 148-d finishing period

	Variety			Level			*P* value		
Item	CDC Cowboy	CDC Copeland	Xena	LOW	HIGH	SEM	V	L	V × L
Initial shrunk BW[a] (kg)	385.0*b*	391.9*a*	394.1*a*	395.8*a*	384.9*b*	1.49	< 0.01	< 0.01	0.45
Final shrunk BW[a] (kg)	620.1	631.4	626.8	623.1	629.0	3.55	0.15	0.21	0.31
ADG (kg)	1.59	1.62	1.57	1.54*b*	1.65*a*	0.022	0.46	< 0.01	0.33
DMI (kg d^{-1})	10.2	10.3	10.1	9.9*b*	10.5*a*	0.12	0.65	< 0.01	0.37
DMI as % of BW	2.03	2.01	1.97	1.94*b*	2.06*a*	0.021	0.29	< 0.01	0.58
NDF intake (kg d^{-1})	2.13	2.08	2.00	1.94b	2.19a	0.025	0.14	< 0.01	0.84
NDF intake (% of BW)	0.42	0.41	0.39	0.38b	0.43a	0.008	0.06	< 0.01	0.87
G:F[b]	0.156	0.158	0.156	0.156	0.158	0.0023	0.87	0.57	0.77
NE_m[c] (Mcal kg^{-1} DM)	2.06	2.10	2.09	2.09	2.07	0.023	0.63	0.43	0.88
NE_g[c] (Mcal kg^{-1} DM)	1.40	1.43	1.42	1.43	1.41	0.021	0.61	0.44	0.85
NE_g[c] intake (Mcal d^{-1})	14.24	14.63	14.33	14.09b	14.70a	0.181	0.38	0.02	0.35

Note: Barley silage:barley grain ratio for LOW inclusion was 1:17 and 1:5 for HIGH inclusion. V, variety; L, level of inclusion; V × L, interaction between variety x level of inclusion; SEM, pooled standard error of mean. ADG, average daily gain; DMI, dry matter intake; G:F, gain:feed; NE_m and NE_g, net energy of maintenance and gain. Means within a row not sharing a lower cased letter differ significantly at the P < 0.05 level.

[a]Shrunken BW calculated as 96% of live weight (NRC, 1996).

[b]G:F is calculated as ADG/DMI.

[c]Calculated based on performance (Zinn and Shen 1998; Zinn et al. 2002).

backgrounding compensated for their lower weight by the end of the finishing phase. This is evident from steers fed the HIGH silage finishing diets having greater ($P < 0.01$) ADG (1.65 vs. 1.54 kg), DMI (10.5 vs. 9.9 kg d^{-1}) and DMI as a % of BW (2.06 vs. 1.94%) but not G:F (0.158 vs. 0.156; $P > 0.05$) as compared to those fed LOW silage finishing diets. The greater weight gain of cattle fed the HIGH silage inclusion finishing diets is interesting as these diets contained 10% less barley grain (77.0 vs. 87.0%, % DM basis) relative to LOW silage inclusion diets. This discrepancy can be explained on the basis that steers fed the HIGH silage inclusion finishing diets exhibited compensatory growth, as their DMI and ADG were restricted by gut fill during backgrounding. This restriction, particularly as it relates to DMI was eliminated during finishing as DMI is no longer restricted by gut fill but rather by dietary energy concentration (Allen 2000). Yambayamba and Price (1991) and Sainz et al. (1995) reported that beef cattle exhibit a rapid and efficient growth when placed on full feed following a period of feed restriction. For example, Sainz et al. (1995) reported greater DMI (11.7 vs. 9.0 kg) and daily empty BW gain (1.74 vs. 1.22 kg d^{-1}) for steers on a similar finishing diet that had been previously fed a forage vs. concentrate based backgrounding diet, respectively. Other studies have reported results where backgrounding performance influenced subsequent finishing performance. In a meta-analysis on the effect of nutrition and management during the backgrounding phase on subsequent finishing performance, Lancaster et al. (2014) reported that ADG ($r^2 = 0.30$) and G:F ($r^2 = 0.49$), but not DMI ($r^2 = 0.01$) during finishing were negatively related to backgrounding ADG while finishing ADG ($r^2 = 0.18$) and G:F ($r^2 = 0.20$) were negatively related to initial finishing BW. Similarly, in a study on carry over effects of backgrounding systems on feedlot performance and carcass characteristics, Reuter and Beck (2013) reported that steers having greater ADG on a forage-based backgrounding diet had lower ADG and DMI ($P < 0.01$) but greater HCW ($P < 0.01$)

during finishing relative to steers having a lower backgrounding ADG. In contrast, Loken et al. (2009) reported minimal effect of backgrounding DMI, ADG and EBWT on finishing performance.

Steers fed HIGH and LOW silage finishing diets had similar G:F ratio and averaged 0.157 ± 0.007 across treatments. Variety of barley silage and level of inclusion did not affect NE_m or NE_g content as calculated from BW, DMI and ADG and averaged 2.08 ± 0.07 Mcal kg $^{-1}$ DM and 1.42 ± 0.06 Mcal kg $^{-1}$ DM, respectively (Mean ± SD; Table 4.5). These values are somewhat greater than the NE_m and NE_g content calculated from chemical composition (Table 4.3) where HIGH silage diets had lower NE_m (1.79 vs. 1.85 Mcal kg $^{-1}$ DM; $P < 0.01$) and NE_g (1.17 vs. 1.22 Mcal kg $^{-1}$ DM; $P < 0.01$) relative to LOW silage diets. However, it should be noted that the steers fed HIGH silage diets during finishing had greater than expected growth, possibly due to compensatory gain. Similar NE_g and G:F across HIGH and LOW silage diets indicate that the improved ADG (1.65 vs. 1.54 kg d^{-1}) of steers fed HIGH silage diets was in response to increased DMI (10.5 vs. 9.9 kg).

There was no effect ($P > 0.05$) of barley variety or level of inclusion on any of the performance parameters when measured over the entire feeding period (Table 4.6). As discussed, poorer performance of steers fed HIGH silage diets during backgrounding was compensated by improved DMI and ADG during finishing. Steers fed HIGH silage diets averaged 10.8 kg less in BW than steers fed LOW silage diets at the end of backgrounding while during finishing they gained 17 kg more so that weights were not significantly different at the time of slaughter.

Carcass characteristics were not affected by barley variety or level of inclusion except that HCW of steers fed CDC Copeland was greater ($P < 0.05$) relative to those fed CDC Cowboy

Table 4. 6. Effect of silage barley varieties and their inclusion level in diet on overall performance of steers

	Variety		Level				*P* value		
Item	CDC Cowboy	CDC Copeland	Xena	LOW	HIGH	SEM	V	L	V × L
Initial shrunk BW[a] (kg)	307.3	307	306.8	307.1	307	0.23	0.51	0.64	0.27
Final shrunk BW[a] (kg)	620.1	631.4	626.8	623.1	629	3.55	0.15	0.21	0.31
ADG (kg)	1.45	1.50	1.48	1.46	1.49	0.016	0.16	0.16	0.36
DMI (kg d^{-1})	9.41	9.64	9.43	9.39	9.6	0.104	0.32	0.12	0.26
DMI (% of BW)	2.03	2.05	2.02	2.02	2.05	0.021	0.59	0.22	0.43
G:F[b]	0.154	0.156	0.157	0.156	0.155	0.0018	0.63	0.73	0.91
NE_m[c] (Mcal kg^{-1} DM)	1.99	2.00	2.02	2.01	2.00	0.019	0.71	0.69	0.86
NE_g[c] (Mcal kg^{-1} DM)	1.33	1.35	1.36	1.35	1.34	0.017	0.63	0.64	0.84

Note: Barley silage barley grain ratio for LOW inclusion was 1:12 and 1:4 for HIGH inclusion based on number of days of backgrounding and finishing and levels of inclusion in the diet. V, variety; L, level of inclusion; V × L, interaction between variety × level of inclusion; SEM, pooled standard error of mean. ADG, average daily gain; DMI, dry matter intake; G:F, gain:feed; NE_m and NE_g, net energy of maintenance and gain. Means within a row not sharing a lower cased letter differ significantly at the $P < 0.05$ level.

[a]Shrunken BW calculated as 96% of live weight (NRC, 1996).
[b]G:F is calculated as ADG/DMI
[c]Calculated based on performance (Zinn and Shen 1998; Zinn et al., 2002).

Table 4. 7. Effect of silage barley varieties and their inclusion level in diet on carcass characteristics of feedlot steers

	Variety			Level			*P* value		
Item	CDC Cowboy	CDC Copeland	Xena	LOW	HIGH	SEM	V	L	V × L
Final shrunk BW[a], kg	620.1	631.4	626.8	623.1	629.0	3.35	0.15	0.21	0.31
Hot carcass weight, kg	361.6*b*	370.6*a*	367.7*ab*	365.7	367.6	3.26	0.04	0.50	0.23
Dressing percentage, %	58.4	58.7	58.7	58.7	58.5	0.26	0.33	0.29	0.40
Grade fat[b], mm	8.4	8.8	8.9	8.6	8.8	0.38	0.34	0.65	0.20
Longissimus dorsi area, cm^2	84.3	85.2	85.7	84.5	85.6	1.67	0.73	0.44	0.55
Marbling Score	413.1	422.6	422.4	419.7	419.1	14.52	0.76	0.96	0.62
Quality grade (%)[c]									
Canada AAA	61.5	60.1	64.9	62.9	61.4	7.11	0.79	0.79	0.46
Canada AA	35.4	37.8	32.0	32.9	37.2	7.64	0.75	0.49	0.67
Canada A	1.0	0.0	1.0	0.70	0.70	1.20	0.61	1.00	0.25
Canada B4 (dark)	2.1	2.1	2.1	3.5	0.70	2.30	1.00	0.16	0.59
Yield grade[d]									
Y1	70.4	73.8	66.7	73.2	67.3	6.53	0.56	0.28	0.22
Y2	23.2	20.7	24.8	20.2	25.6	5.26	0.74	0.23	0.56
Y3	6.4	5.5	8.5	6.5	7.1	3.50	0.68	0.83	0.12

Note: Barley silage barley grain ratio for LOW inclusion was 1:12 and 1:4 for HIGH inclusion based on number of days of backgrounding and finishing and levels of inclusion in the diet. V, variety; L, level of inclusion; V × L, interaction between variety x level of inclusion; SEM, pooled standard error of mean. Means within a row not sharing a lower cased letter differ significantly at the $P < 0.05$ level.

[a]Shrunken BW calculated as 96% of live weight (NRC, 1996).

[b]Grade fat is a measure of subcutaneous fat assessed perpendicular to the outside surface, within the fourth quarter of the rib-eye at the minimum point of thickness.

[c]Quality grade: B4, No yield grade; Canada A, Marbling score 300; Canada AA, Marbling score 400; Canada AAA, Marbling score 500; Canada Prime, Marbling score 800 (Canadian Beef Grading Agency, 2009).

[d]Yield grade: Lean meat yield, %: Canada 1 = 59% to more; Canada 2, 58 to 54%; Canada 3, 53% or less.

(Table 4.7). The greater HCW of steers fed CDC Copeland corresponds to the numerically greater final finishing BW of steers fed this silage (631 ± 47.0 kg; Mean ± SD) relative to those fed CDC Cowboy (620 ± 46.0 kg; Mean ± SD). Yield and quality grades were similar to other studies in which steers were fed barley silage-barley grain based finishing diets (He et al. 2013; Nair et al. 2015).

As indicated, no variety × level interaction was observed for any of the measured backgrounding, finishing or carcass characteristics. This did not fit our hypothesis that barley varieties reported to have a greater $NDFD_{30h}$ will allow for greater substitution of barley grain at equal dietary energy density. Based on the $NDFD_{30h}$ result of Nair et al. (2016) we expected improved backgrounding and finishing performance for steers fed CDC Cowboy relative to those fed CDC Copeland and Xena. However, as shown in Table 4.1, NDFD of the three barley varieties chosen for the study did not differ. The lack of significant variation in terms of $NDFD_{30h}$ among the barley varieties for silage in the present study could potentially be the reason for the absence of any variety × level interaction. As previously reported, this signifies the difficulty in choosing barley forage varieties based on a single chemical or nutritional parameter like $NDFD_{30h}$ as it may not be possible to obtain consistent plant characteristics over multiple crop years. Further research in terms of genetic selection is required for nutrient and NDFD characteristics before these nutritional parameters can be used as selection criteria by producers to make decisions on which variety to grow for silage.

4.5 Conclusion

The variety of barley used for silage and level of inclusion significantly affected backgrounding performance with steers fed CDC Cowboy exhibiting lower EBWT and ADG

relative to those fed CDC Copeland and Xena. Greater NDF content in the diets of steers fed CDC Cowboy likely restricted the DM and NE_g intake resulting in poorer performance. Greater silage inclusion resulted in poorer backgrounding performance. Backgrounding performance was influenced to a greater extent by the NDF content of the diet than by $NDFD_{30h}$. Greater inclusion of silage improved the ADG and DMI of finishing steers irrespective of variety likely due to compensatory growth. Over the entire study, performance and carcass characteristics were not impacted by treatment except for carcass weight where steers fed CDC Copeland had heavier carcasses relative to those fed CDC Cowboy or Xena. These results indicate the difficulty in choosing barley forage varieties for silage based on a single nutrient parameter like $NDFD_{30h}$ when factors such as environmental conditions can influence plant growth and nutrient composition.

Greater NDF content in CDC cowboy and HIGH silage diets during backgrounding resulted in poorer performance of steers due to restriction in DMI by gut fill. It would be valuable to evaluate how greater NDF content of these diets affect the ruminal fermentation, ruminal passage, total tract NDF digestibility and N retention. Moreover, steers fed HIGH silage diets during finishing had compensatory gain as indicated by greater DMI and ADG. Relatively greater NDF content in finishing diets than conventional high grain diets is expected to improve the rumen pH parameters and total tract digestibility. Further research is warranted as to what extent variety and level of inclusion of barley varieties impact ruminal fermentation, ruminal NDF digestibility, total tract nutrient digestibility and digestible energy content of the diet.

5.0 Effect of variety and level of inclusion of barley silage selected to vary in NDF digestibility on ruminal fermentation and nutrient digestibility of feedlot heifers fed backgrounding and finishing diets

5.1 Abstract

Two metabolism studies were carried out to evaluate effect of barley variety and level of inclusion of barley silage on ruminal fermentation and total tract nutrient digestibility using yearling beef heifers (531 ± 46.0 kg and 570 ± 54.0 kg respectively) fed backgrounding (Study 1) and finishing (Study 2) diets. Both studies were 4 × 4 Latin square designs with 2 (barley varieties; CDC Cowboy and Xena) by 2 (dietary level of inclusion; LOW and HIGH) factorial arrangement of treatments. Barley silage:barley grain ratio was 1:1 (LOW) and 2:1 (HIGH) in Study 1 and 1:17 (LOW) and 1:5 (HIGH) in Study 2. Barley varieties did not vary in $NDFD_{30h}$ and averaged 37.1 ± 1.86% (% NDF basis) across varieties. Heifers fed CDC Cowboy had greater ($P = 0.05$) mean spot ruminal pH and lower ($P = 0.01$) duration under pH 5.8 relative to those fed Xena in Study 1. Heifers fed CDC Cowboy HIGH and Xena HIGH silage diets had greater ($P < 0.01$) mean ruminal pH than those fed CDC Cowboy LOW silage diets in Study 2. Moreover, heifers fed HIGH silage diets had lower ($P = 0.05$) duration under ruminal pH 5.8. Ruminal fermentation parameters were similar across treatments in both studies. The acetate:propionate ratio of heifers fed CDC Cowboy HIGH and Xena HIGH was greater ($P < 0.01$) than that of heifers fed CDC Cowboy LOW in Study 2. Mean ruminal NH_3-N concentration was greater ($P < 0.01$) for heifers fed CDC Cowboy HIGH relative to CDC Cowboy LOW and Xena HIGH in Study 1. Total tract nutrient digestibility did not vary among treatments in both studies. Total N intake and fecal N excretion were greater ($P \leq 0.03$) for heifers fed LOW relative to HIGH silage diets in Study 1. Moreover, heifers fed LOW silage

diets had greater apparent total N retention relative to those fed HIGH silage diets in Study 1. These results indicate that barley variety has minimal impact on total tract nutrient digestibility although high NDF content can lead to a decrease in DE intake. High NDF barley varieties and greater inclusion levels also improve ruminal pH conditions which may improve total tract fiber digestibility in finishing diets.

Key words: barley silage, variety, NDFD, ruminal fermentation, nutrient digestibility

5.2 Introduction

Whole-crop barley (*Hordeum vulgare* L.) is the major forage source for silage for feedlot and dairy operations in western Canada due to superior forage quality (Baron et al. 2000) and ensiling characteristics of barley among small grain species (Kaulbars and King 2004). Barley is commonly harvested at mid-dough for optimizing nutrient quality with DM yield (McAllister and Hristov 2000; Kaulbars and King 2004). However, in a recent evaluation of common barley varieties grown for silage in western Canada, Nair et al. (2016a) reported that barley varieties harvested at mid-dough varied in nutrient composition and NDF digestibility (NDFD). These authors reported that 30 h NDFD ($NDFD_{30h}$) of CDC Cowboy was greater relative to Xena, with CDC Copeland intermediate. However, these varieties did not vary in $NDFD_{30h}$ when seeded, treated and harvested in a similar manner in a subsequent feedlot study. Moreover, steers fed a barley variety with a greater NDF content (CDC Cowboy vs CDC Copeland or Xena) or those fed silage at greater dietary inclusion (HIGH vs LOW) exhibited lower DMI and poorer performance during backgrounding. However, it is not clear as to why animal performance was influenced to the nature of the barley variety or the level of barley silage included in the diet.

Detailed studies on ruminal fermentation and total tract nutrient utilization may provide insights into the reasons for the responses noted.

Greater DMI of cattle fed high NDFD forage has been attributed to the increased ruminal degradation of forage NDF and consequent faster NDF disappearance and ruminal particulate passage rate (Oba and Allen 1999). Greater NDFD is also correlated to greater TDN content and availability of dietary energy (Hoffman and Combes 2004). It may also potentially allow for the substitution of a portion of barley grain with high NDFD silage while still achieving ant equal energy density, reducing the incidence of subacute ruminal acidosis (SARA). Soita et al. (2003) reported relatively greater mean ruminal pH, acetate, A:P ratio and ruminal NH_3-N concentration and lower propionate levels for beef steers fed diets with 50:50 relative to 20:80 barley silage:barley grain diet. However, there is very limited information on the effect of $NDFD_{30h}$ of barley varieties and the level of inclusion on ruminal fermentation, total tract digestibility characteristics and particulate passage rate in beef heifers. The objectives of this study were to evaluate the effect of feeding barley varieties previously shown to vary in $NDFD_{30h}$ and the level of inclusion on ruminal fermentation, total tract digestibility characteristics and digestible energy content for growing beef heifers fed backgrounding and finishing diets.

5.3 Materials and Methods

5.3.1 Animal and Housing

Two studies were conducted using backgrounding (Study 1) and finishing diets (Study 2). Four yearling Hereford × Gelbvieh cross heifers (531 ± 46.0 kg and 570 ± 54.0 kg, Mean ± SD) were used for Study 1 and 2, respectively. For both studies, heifers were housed at the Livestock Research Facility of the University of Saskatchewan in individual indoor pens with a floor space

of 9 m^2. Each pen was equipped with a feeder, automatic water bowl and rubber floor mat. All four heifers were fitted with soft rubber cannula (10 cm diameter; Barr Diamond, Parma, ID). Heifers were fed a diet containing 75:25 barley silage:concentrate *ad libitum* until the beginning of the respective studies and were cared for as per the guidelines of the Canadian Council on Animal Care (CCAC 2009).

5.3.2 Experimental Design

Study 1

The study was designed as a 4 × 4 Latin square with a 2 (barley variety) by 2 (dietary level of inclusion) factorial arrangement of treatments. The two barley varieties (CDC Cowboy and Xena) were previously shown (Nair et al. 2016a) to vary in $NDFD_{30h}$ (% NDF basis) with CDC Cowboy having a greater $NDFD_{30h}$ (37.0%) than Xena (28.8%). Both the varieties were grown and ensiled without the addition of silage preservatives at the University of Saskatchewan in the spring/summer of 2014. The study lasted 124 d with four periods of 31 d each. The first 12 d of each period were used for diet adaptation; voluntary intake was measured from d 13 to 18. Body weights were taken at the beginning and end of voluntary intake and used to calculate intake as a % of BW. Infusion of markers (Chromium and Ytterbium) for evaluating passage rate started on d 13 and continued until d 23. Days 15 to 18 were used for measuring rumen pH using in-dwelling pH probes. Ruminal fluid and omasal samples were collected from d 20 to 23. From d 23 of each period, heifers were fed at 95% of voluntary intake. On d 25, urinary catheters were inserted and total urine and fecal collections were carried out from d 26 to 31.

Study 2

The experimental design was similar to Study 1 and lasted 112 d with four periods of 28 d. The first 18 d consisted of 12 d of diet adaptation and 6 d of voluntary intake with body weight measurements on d 13 and 18 and ruminal pH measurements using in-dwelling pH probes from d 15 to 18. On d 19, ruminal fluid was collected every 2 h over a 24 h period. From d 20 of each period, heifers were fed at 95% of voluntary intake. On d 22, urinary catheters were inserted and total urine and fecal collections were carried out from d 23 to 28.

5.3.3 Treatment and Dietary Composition

Treatments included two barley silage varieties (CDC Cowboy and Xena; Table 5.1) fed at two inclusion levels (LOW and HIGH; Table 5.2). Barley silage:barley grain ratio (DM basis) was maintained at 1:1 for the LOW and 2:1 for the HIGH barley silage inclusion diets in Study 1 and 1:17 for the LOW and 1:5 for the HIGH inclusion diets in Study 2. HIGH silage inclusion levels were achieved by replacing a portion of barley grain in the LOW silage inclusion diets with the corresponding barley silage variety. Inclusion of hay was kept constant across the treatments in Study 1 while that of canola meal and supplement was kept similar across treatments in both studies. There was an 18-d, 6-step dietary transition period with dietary change occurring every 4^{th} day in Study 2 by which the heifers were transitioned from the backgrounding diet to the final finishing diet. All diets were formulated to meet or exceed National Research Council (NRC 2000) requirements for CP, energy, minerals and fat-soluble vitamins for beef heifers.

Table 5. 1. Composition of feed ingredients used for the evaluation of variety and level of inclusion of barley silage for feedlot heifers in Studies 1 and 2

	Barley silage (n = 4)		Bromegrass hay	Barley grain	Canola meal	Supplement
	CDC Cowboy	Xena	(n = 4)	(n = 4)		
Chemical composition (% DM basis)[a] unless otherwise stated						
Study 1						
CP	11.3 ± 0.14	11.3 ± 0.39	8.23 ± 0.61	12.4 ± 0.24	39.3	28.6
EE	2.25 ± 0.26	2.30 ± 0.07	1.30 ± 0.19	2.02 ± 0.27	3.43	1.96
ADF	36.3 ± 0.46	31.3 ± 1.30	42.2 ± 2.55	8.50 ± 0.74	22.0	9.0
NDF	54.3 ± 0.95	48.4 ± 2.10	59.9 ± 2.18	17.1 ± 0.25	28.6	17.9
Lignin	5.11 ± 0.12	4.56 ± 0.31	7.53 ± 0.64	2.75 ± 0.05	10.0	1.48
Starch	9.15 ± 0.89	15.9 ± 1.03	0.35 ± 0.24	61.7 ± 1.10	1.4	0.60
Ash	8.38 ± 0.65	7.67 ± 0.54	7.92 ± 0.58	2.89 ± 0.06	8.01	32.6
Ca	0.44 ± 0.01	0.41 ± 0.01	0.66 ± 0.05	0.08 ± 0.02	0.82	10.0
P	0.35 ± 0.01	0.39 ± 0.01	0.10 ± 0.01	0.35 ± 0.01	1.18	0.65
Study 2						
CP	12.0 ± 0.10	11.5 ± 0.22	-	12.8 ± 0.70	40.0	27.2
EE	2.54 ± 0.23	2.55 ± 0.18	-	2.03 ± 0.11	3.22	2.82
ADF	36.6 ± 2.61	32.5 ± 1.38	-	7.83 ± 0.66	22.9	9.6
NDF	54.5 ± 2.76	50.9 ± 1.52	-	17.2 ± 0.54	29.6	18.8
Lignin	5.43 ± 0.36	4.46 ± 0.23	-	2.54 ± 0.35	10.45	1.53
Starch	9.48 ± 3.56	17.8 ± 1.33	-	61.9 ± 2.0	0.6	2.3
Ash	9.29 ± 0.63	8.06 ± 0.52	-	2.80 ± 0.06	8.03	33.2
Ca	0.46 ± 0.01	0.40 ± 0.02	-	0.08 ± 0.01	0.84	9.91
P	0.36 ± 0.02	0.39 ± 0.01	-	0.41 ± 0.01	1.26	0.61
NDF digestibility parameters						
$NDFD_{6h}$, % NDF	6.05 ± 2.45	4.71 ± 2.22	-	-	-	-
$NDFD_{30h}$, % NDF	37.6 ± 3.50	36.9 ± 2.96	-	-	-	-

Note: CP, crude protein; EE, ether extract; ADF, acid detergent fiber; NDF, neutral detergent fiber; Ca, calcium; P, phosphorus; $NDFD_{6h}$ and $NDFD_{30h}$, NDF digestibility after 6 and 30 h *in vitro* incubation using Daisy^{II} incubation system

[a]Analyzed at Cumberland Valley Analytical Services, Inc., Hagerstown, MD

Table 5. 2. Composition of diets containing CDC Cowboy or Xena barley silage at two levels of inclusion in Studies 1 and 2

	Treatment			
	CDC Cowboy		Xena	
	LOW	HIGH	LOW	HIGH
Diet composition (% DM basis)				
Study 1				
Barley silage	40.6	54.0	40.3	54.0
Bromegrass hay	9.4	9.3	9.6	9.5
Barley grain	40.8	27.0	41.0	27.0
Canola meal	5.5	5.8	5.6	5.6
Supplement	3.7	3.9	3.5	3.9
Study 2				
Barley silage	5.0	14.8	5.0	15.0
Barley grain	86.8	76.9	86.9	76.7
Canola meal	3.6	3.6	3.6	3.6
Supplement	4.6	4.7	4.5	4.7
Supplement composition for Study 1 and Study 2 (% DM basis)				
Pea/lentil screenings	55.1	55.1	55.1	55.1
Limestone	23.8	23.8	23.8	23.8
Urea	4.3	4.3	4.3	4.3
Corn DGS	3.7	3.7	3.7	3.7
Prairie pride pellets[a]	3.2	3.2	3.2	3.2
Tallow	1.0	1.0	1.0	1.0
Mineral, vitamin premix[b]	8.9	8.9	8.9	8.9

Note: Barley silage:barley grain ratio is 1:1 for LOW inclusion and 2:1 for HIGH inclusion during Study 1 and 1:17 for LOW and 1:5 for HIGH inclusion diets during Study 2.

[a]Contains wheat bran, wheat shorts, wheat middlings, number 1 and 2 feed screenings, barley grain and refuse screenings with guaranteed minimum analysis of 15% crude protein and 3% crude fat and maximum 12.5% crude fiber.

[b]Mineral, vitamin premix provided 10.8% Ca, 0.54% P, 1.9% Na, 0.54% Mg, 1.1% K, 0.31% S and 5.0 mg Co, 17.3 mg I, 207.9 mg Fe, 645.5 mg Mn, 1.45 mg Se, 643.5 mg Zn and 701.2 mg monensin per kg and 53,000 IU vitamin A, 5,400 IU vitamin D3 and 540 IU vitamin E per kg supplement DM.

Monensin sodium was provided at 33 mg kg^{-1} DM and melengestrol acetate (MGA) at 0.4 mg per heifer per day and included in the vitamin-mineral pellet. Calcium:phosphorus ratio was formulated to range from 1.5:1 to 2:1. All feed ingredients were hand-mixed and fed in two equal proportions at 0800 and 1600 h. All heifers were fed *ad libitum* until day 23 of each period by ensuring 0.5-0.75 kg of orts. Orts were weighed every day and sub-sampled for determination of DM content during the voluntary intake period and for nutrient analysis during total tract collection.

Both CDC Cowboy and Xena were grown on non-irrigated land at the University of Saskatchewan. Seeding, harvest and ensiling management were similar across varieties and described in Chapter 4. Both Study 1 and 2 utilized the same silage varieties that were used for a concurrent feedlot study (Nair et al. 2016b). Dry rolled barley grain and canola meal were purchased from commercial sources. Pelleted supplement was sourced from Federated Co-op (Saskatoon, SK). Silage and hay samples were taken every wk to determine DM content and to adjust daily feeding amounts as necessary. Rolled barley grain, canola meal and supplement samples were collected every 2 wk, DM was determined and samples were stored for later analysis. All samples were composited on a period basis.

5.3.4 In-dwelling Ruminal pH Measurement

Ruminal pH was measured using an in-dwelling ruminal pH system (Dascor, Escondido, CA) as described by Penner et al. (2006). Probes were standardized using standard buffers (pH 4 and 7). The system measured ruminal pH every min for 72 h starting at 0800 h from d 16 to 19 for Study 1 and d 15 to 18 for Study 2. After 72 h, probes were removed from the rumen, washed and data downloaded. The mV data were converted to pH data using the calculated slope and y-intercept

values determined during calibration. The pH data were averaged by min and then mean, maximum and minimum pH values were determined for each heifer. The duration (min d^{-1}) and area (min d^{-1} × pH) under pH 5.8 and 5.5 was determined in Study 1 while pH 5.2 was also determined in Study 2 to describe mild (pH 5.8 to 5.5), moderate (pH 5.5 to 5.2) and severe acidosis (pH < 5.2) as per Nocek (1997) and Penner et al. (2007).

5.3.5 Marker Infusion

To quantify omasal flow of NDF in Study 1, indigestible NDF (INDF; Reynal et al. 2005), $YbCl_3$ (Siddons et al. 1985) and CrEDTA (Udén et al. 1980) were used as digesta markers for the large particle (LP), small particle (SP) and fluid (FP) phases respectively, as described by Chibisa et al. (2012). Briefly, a priming dose (500 ml) of the 2 marker solutions ($YbCl_3$ and Cr-EDTA) equivalent to half the daily dose (~1 L) was administered into the rumen via the rumen cannula on d 13. Subsequently, the marker solution was infused into the rumen using a peristaltic pump (Model 205U, Watson-Marlow, Cornwall, UK) for 10 d (d 13 to 23). Both Cr-EDTA and Yb marker solutions were prepared separately and stored in individual containers. Markers were infused at a constant rate of 1 L d^{-1} providing 2.77 g of Cr (Binnerts et al. 1968) and 3.35 g of Yb (Brito et al. 2006) per day. The amount of marker solution infused each day was recorded. A 50 ml sample of the marker solution infused for each period per heifer was stored for analysis at a later stage.

Omasal digesta samples were collected as described by Huhtanen et al. (1997). Samples were collected under vacuum from the omasal canal into a collection flask. Samples were collected from each heifer at 0600, 1200 and 1800 h on d 20, 0000, 0800, 1400 and 2000 h on d 21; 0200, 1000, 1600 and 2200 h on d 22 and 0400 h on d 23 so that the composite sample

represented a 24 h collection with a 2 h sample interval. At each collection time, 300 ml of omasal digesta was collected and a 200 ml subsample was frozen for later marker analysis.

5.3.6 Ruminal Fluid Collection

To determine ruminal fermentation characteristics, ruminal fluid was collected from all four heifers along with omasal samples from d 20 - 23 in Study 1 and at 2 h intervals starting at 0800 on d 19 of each period in Study 2. About 250 ml of ruminal fluid from four different regions of the rumen (cranial ventral, caudal dorsal, caudal ventral region and rumen mat) was collected and strained through four layers of cheese cloth. using a model 265A portable pH meter (Orion Research Inc., Beverly, MA), the spot pH was measured immediately in duplicate and recorded in both Study 1 and 2. Two, 10 ml samples of ruminal fluid were collected and frozen at -20ºC for VFA [mixed with 2 mL, 25% (w/v) metaphosphoric acid solution] and ammonia [mixed with 2 ml, 1% (v/v) sulphuric acid solution] analysis.

5.3.7 Ruminal Fluid Volatile Fatty Acid Analysis

Tubes containing ruminal fluid for VFA analysis were thawed overnight at 4ºC and thoroughly mixed prior to centrifugation at 12 000 *g* for 10 min at 4ºC using a Beckman Centrifuge (Model Avanti J-E; Palo Alto, CA). The supernatant (1.5 ml) was transferred into microcentrifuge tubes (VWR™, Radnor, PA) and centrifuged again at 16 000 *g* for 10 min at 4ºC (Beckman Coulter™, Brea, CA). Following this step, 1 ml of supernatant was mixed with 0.2 ml of internal standard (isocaproic acid) in a 2 ml screw top glass vial (Agilent Technologies™, Santa Clara, CA). Prepared samples were loaded into the autosampler of an Agilent 6890 series gas chromatography system (Agilent Technologies™, Santa Clara, CA) with an Agilent 7683 series 5 µL injector. The unit was equipped with a Zebron ZB-FFAP high performance GC capillary

column (30 m × 320 µm × 0.25 µm; Phenomenex, Torrance, CA) with a flow rate of 35 ml min^{-1}, and an Agilent split focus liner (Agilent Technologies™, Santa Clara, CA) at a split ratio of 10:1. Column conditions were an initial temperature of 90ºC held for 0.1 min before an increase of 10ºC min^{-1} to 170ºC. Injector temperature was set at 170ºC while the detector temperature was 250ºC. A mixed standard containing known amounts of acetic, propionic, butyric, isobutyric, valeric, isovaleric and caproic acids was used to develop a calibration curve for analysis of unknown samples. The concentration of each VFA (mmol L^{-1}) was measured by comparing peak areas with that of the internal standard (isocaporic acid). Samples for analysis were prepared daily and kept at 4ºC until the initiation of the analysis run to prevent volatilization.

5.3.8 Ruminal Ammonia

Ruminal fluid samples for analysis of ammonia were thawed overnight at 4ºC and mixed thoroughly before centrifuging at 14 000 *g* for 10 min at 4ºC. The supernatant was used for analysis of ammonia by the phenol-hypochlorite procedure as outlined by Broderick and Kang (1980).

5.3.9 Total Collection of Urine and Feces

Total collection of urine and feces was carried out for the last five days of each period in both Study 1 and Study 2. Heifers were fitted with bladder catheters (Bardex 75 cc Lubricath® 2-way Foley Catheter, C. R. Bard Inc., Covington, GA) 24 h prior to the start of total collection. Urinary catheters were attached to Nalgene plastic tubes and connected to 20 L Nalgene carboys containing 150 ml concentrated HCl to prevent volatilization of urinary ammonia. Urine output was recorded daily, mixed and 10% was subsampled and frozen at -20ºC. At the end of each period, the composite urine sample was thawed, mixed and 500 ml was subsampled for each

animal and stored at -20ºC for analysis of urinary N. Total feces were collected by scraping the feces off the floor every 2 h from 0600 to 2200 and every 4 h thereafter. Daily fecal output was recorded, mixed and 2.5% of total weight was subsampled into pre-weighed aluminum trays and frozen at -20ºC. At the end of total collection, fecal samples from each period were dried in a forced air oven at 55ºC for 120 h and composited by animal for each period prior to being stored for analysis at a later stage.

5.3.10 Sample Analysis

Barley silage samples were dried for 72 h while hay, barley grain, canola meal and mineral-vitamin supplement were dried for 48 h in a forced air oven at 55ºC. A Christy & Norris Lab mill (Christy Turner Ltd., Chelmsford, UK) with 1 mm screen was used to grind forage samples and orts while a Retsch ZM 100 grinder (Retsch, Haan, Germany) was used to grind concentrate and fecal samples through a 1 mm screen. Silage samples were analyzed by Near Infrared Reflectance spectroscopy (NIR) at Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) with the exception of NDF which was analyzed by wet chemistry. All concentrate, orts and fecal samples were analyzed by Cumberland Valley Analytical Services (CVAS, Hagerstown, MD) for DM at 135ºC [method 930.15; Association of Official Analytical Chemists (AOAC) 2000], CP (method 990.03; AOAC 2000) using a Leco FP 528 Nitrogen Combustion Analyzer (Leco, St. Joseph, MI), ADF (method 973.18; AOAC 2000), starch as described by Hall (2009), fat using a tecator extraction unit (method 2003.05; AOAC 2000) and ash (method 942.05; AOAC 2000). The method of Van Soest et al. (1991) with the addition of amylase and sodium sulfite was used to analyze NDF content. Fat content of fecal samples was determined by acid ether extraction (method 2003.05; AOAC 2000). Calcium and phosphorus were analyzed after dry-ashing (method 927.02 and 965.17, respectively, AOAC 2000). Gross energy of forage,

concentrate, orts, and fecal samples was estimated using a Parr 1281 bomb calorimeter (Parr Instrument Company, Moline, IL) and urinary nitrogen using the Kjeldahl method (method 984.13; AOAC 2000).

Composite omasal digesta samples were processed for marker analysis as per Brito et al. (2009) and Chibisa et al. (2012). Briefly, samples were thawed at room temperature and separated into large particle (LP), small particle (SP) and fluid phase (FP). The composite omasal digesta was squeezed through a single layer of cheese cloth. The solids retained on the cheese cloth were considered to be the LP fraction. The filtrate was centrifuged at 1000 × g for 5 min at 5ºC using a Beckman Centrifuge (Model Avanti J-E; Palo Alto, CA). The resultant pellet was considered the SP fraction and the supernatant the FP fraction. The 3 phases (LP, SP and FP) were freeze dried and then ground to pass through a 1 mm screen using a Christy & Norris Lab mill (Christy Turner Ltd., Chelmsford, UK). Respective phases were processed to determine Cr and Yb concentrations as per Vicente et al. (2004). Briefly, duplicate 1 g samples from each of the 3 phases were ashed at 550 ºC for 8 h in a muffle furnace. After cooling, 15 ml of 1.5 mol L^{-1} HNO_3 containing 0.2% KCl was added to the samples and boiled for 3 min. After cooling, the mixture was diluted to 100 ml with double distilled water and filtered using Whatman No 1 filter paper. The supernatant was stored in 50 ml plastic vials at room temperature until analyzed using an atomic absorption spectrophotometer (ice 3000 series, Thermo scientific, Waltham, MA) equipped with a Cetac ASX 260 autosampler (Cetac technologies, Omaha, NE).

Indigestible NDF (INDF) concentrations in LP, SP, TMR and orts but not FP were measured as per Ahvenjärvi et al. (2000). Briefly, 1.5 g of LP, 3.0 g of TMR and orts and 3.5 g of SP were weighed in triplicate into 5 cm × 10 cm custom-made *in situ* bags (6 µm pore size, petex 07-6/5, Ankom technology, Macedon, NY). Bags were randomly assigned to one of 7

ruminally cannulated beef heifers fed an 85:15 barley silage:concentrate diet (% DM basis). Sample bags were placed in laundry bags with a weight to keep the samples immersed and placed into the ventral sac of rumen and incubated for 12 d. After incubation, the bags were removed from the rumen and rinsed in cold water until the rinse water was clear. Bags were then soaked in cold water for 30 min and dried at 55ºC for 48 h. After drying, the weight of the bags with residue was recorded before NDF analysis. Following analysis, the omasal true digesta (OTD) was reconstituted from the LP, SP and FP using the triple marker method of France and Siddons (1986). To determine the flow of NDF to the omasum, the OTD samples were analyzed for NDF with the addition of amylase and sodium sulfite.

5.3.11 Statistical Analysis

The mixed model procedure of SAS (version 9.4; SAS Institute, Inc., Cary, NC) was used to compare the effect of treatment on DMI, rumen fermentation (pH, VFA, osmolality, and NH_3-N), omasal NDF digestibility, flow rate and apparent total tract nutrient digestibility. Both studies were Latin squares with 2 × 2 factorial arrangement of treatments. The effect of variety (V), level of inclusion (L) and variety × level interaction (V × L) were included in the model. Heifer was treated as a random effect and treatment and period as fixed effects. In both studies, ruminal fermentation data including in-dwelling rumen pH measurements, omasal NDF digestibility and flow rate, total tract digestibility and nitrogen balance data were analyzed as Latin square design, while repeated measures analysis was conducted for ruminal VFA proportions and concentration, ammonia and spot pH samples with the fixed effect of time (day) and treatment × time (day) interaction included in the model. Denominator degrees of freedom were determined using the Kenward-Roger option. Normality was tested using univariate procedure of SAS software with the Shapiro-Wilk test. The covariance structure with the lowest

AIC and BIC values was selected (Littell et al. 1996). Significant differences and trends were declared at $P < 0.05$ and $0.05 < P < 0.10$, respectively.

5.4 Results and Discussion

5.4.1 Chemical and Nutrient Profile of Diets

Composition of the two barley silage varieties and other feed ingredients used in both studies is presented in Table 5.1. As there was only one silage pile per variety, no statistical analysis was conducted and only means ± SD of samples (n = 4) are presented. Composition of feed ingredients was similar across the studies as evidenced by the mean and SD (Table 5.1). However, the nutrient composition varied between barley silage varieties with CDC Cowboy having a greater ADF, NDF and lignin content and lower starch content relative to Xena. Similar nutrient profiles for barley silage was also reported by Gill et al. (2013) with a greater ADF and NDF content for CDC Cowboy among the six 2-row barley varieties they evaluated. These authors also reported the lowest TDN content for CDC Cowboy, likely due to a lower starch content. Nair et al. (2016a) in a nutritional evaluation of common barley varieties reported a greater ADF, NDF and lower starch content for CDC Cowboy among seven barley varieties. Moreover, CDC Cowboy had a greater ash content than Xena.

Both CDC Cowboy and Xena did not vary in terms of $NDFD_{6h}$ and $NDFD_{30h}$ (% NDF basis) (Table 5.1) with considerable overlap between varieties. The NDFD (6 and 30 h) of both CDC Cowboy and Xena were the same as that reported by Nair et al. (2016b) as both the studies utilized the same silage source. Moreover, in an evaluation of fermentation characteristics of these varieties, Preston et al. (2016a?) reported 34.5 ± 1.7 and 33.4 ± 1.7 % $NDFD_{30h}$ (% NDF basis) respectively for CDC Cowboy and Xena grown in southern Alberta in 2014. However,

these values differ from Nair et al. (2016) who reported that CDC Cowboy had greater $NDFD_{30h}$ (37.0 vs 28.8; % NDF) relative to Xena. Even though CDC Cowboy has similar $NDFD_{30h}$ across studies, Xena had a relatively greater $NDFD_{30h}$ in the present study and in the study of Preston et al. (2016a) relative to that reported by Nair et al. (2016). It should be noted that in the present study and in the study of Preston et al. (2016a), the barley varieties were seeded and treated similarly and harvested on the same day across varieties. However, in the study by Nair et al. (2016), samples of barley silage were harvested and ensiled at mid-dough as determined by the visual evaluation by individual producers across multiple feedlot and dairy operations from varying geographical locations over two crop years. Differences in $NDFD_{30h}$ among barley varieties could be attributed to the variation in environmental growing conditions as well as to relative differences in maturity between studies.

Dietary inclusion levels of the 2 barley varieties in both the studies are presented in Table 5.2. Diet composition in Study 1 and Study 2 was similar to that of the backgrounding and finishing diets of the concurrent feedlot study (Nair et al. 2016b), except that the supplement used for the metabolism study contained MGA.

Nutrient composition of the diets is presented in Table 5.3. Only main effects are reported as there was no V × L interaction for any of the measured nutrients with the exceptions of a trend ($P = 0.07$) for heifers fed CDC Cowboy HIGH diets in Study 1 having greater ADF content relative to those fed Xena LOW (data not shown). Crude protein and EE content of the diets were not affected by the V or L and averaged 13.6 ± 0.05 % and 2.1 ± 0.04 % (% DM basis), respectively, across diets and studies. The ADF, NDF, ash and P content was greater while starch content was lower for diets containing CDC Cowboy relative to Xena in Study 1, while variety of barley silage had no effect on the y concentration of these constituents in Study 2.

Table 5. 3. Nutrient composition of diets containing CDC Cowboy or Xena barley silages at two levels of inclusion in Studies 1 and 2

	Variety		Level			*P* value		
	CDC Cowboy	Xena	LOW	HIGH	SEM	V	L	V × L
Nutrient composition (% DM basis)								
Study 1 (n = 4)								
CP	13.6	13.6	13.6	13.6	0.04	0.80	0.41	0.50
EE	2.1	2.2	2.1	2.1	0.06	0.76	0.49	0.88
ADF	25.6	23.2	22.7	26.1	0.12	<0.01	<0.01	0.07
NDF	39.4	36.6	35.7	40.3	0.22	<0.01	<0.01	0.45
Starch	25.3	28.6	30.3	23.6	0.26	<0.01	<0.01	0.44
Ash	7.4	7.0	6.8	7.6	0.09	0.05	<0.01	0.99
Ca	0.72	0.70	0.67	0.75	0.012	0.15	<0.01	0.59
P	0.38	0.40	0.39	0.40	0.002	<0.01	0.11	1.00
Study 2 (n = 4)								
CP	13.5	13.5	13.5	13.5	0.21	0.82	0.91	0.96
EE	2.2	2.2	2.1	2.2	0.03	0.98	0.24	0.98
ADF	11.3	10.9	9.7	12.4	0.23	0.33	<0.01	0.70
NDF	21.4	21.1	19.5	23.1	0.10	0.18	<0.01	0.98
Starch	51.7	52.5	54.5	49.6	0.66	0.30	<0.01	0.68
Ash	5.0	5.0	4.7	5.3	0.03	0.08	<0.01	0.72
Ca	0.60	0.59	0.57	0.62	0.006	0.27	<0.01	0.78
P	0.45	0.45	0.45	0.45	0.002	0.21	0.91	0.34

Note: Barley silage:barley grain ratio is 1:1 for LOW inclusion and 2:1 for HIGH inclusion during Study 1 and 1:17 for LOW and 1:5 for HIGH inclusion diets during Study 2; SEM, pooled standard error of mean; V, barley variety; L, level of inclusion; V × L, variety × level interaction; CP, crude protein; EE, ether extracr; ADF, acid detergent fiber; NDF, neutral detergent fiber; Ca, calcium; P, phosphorus. SEM, pooled standard error of mean. Values with lowercased letters differ among all treatments ($P < 0.05$). Barley silage:barley grain ratio is 1:1 for LOW and 2:1 for HIGH inclusion in Study 1 and 1:17 for LOW and 1:5 for HIGH inclusion in Study 2.

These observations are similar to that reported in the concurrent feedlot study. Greater fiber and lower starch content of diets containing CDC Cowboy corresponds to the nutrient composition of CDC Cowboy silage relative to Xena (Table 5.1). Similar to the variety effect, there was an effect of level of inclusion of silage variety on nutrient composition of diets in both Study 1 and 2 with HIGH silage diets having greater ADF, NDF, ash and Ca content and lower starch content relative to LOW silage diets.

5.4.2 Ruminal pH

Study 1

Spot sample ruminal pH indicated greater (P = 0.05) mean ruminal pH for heifers fed CDC Cowboy relative to those fed Xena (Table 5.4). Similarly, there was a trend (P = 0.06) for greater mean ruminal pH for heifers fed CDC Cowboy using in-dwelling pH probes. Lower minimum ruminal pH was recorded for heifers fed Xena (P = 0.02) relative to those fed CDC Cowboy. Improvements (i.e. higher) in ruminal pH of heifers fed CDC Cowboy are likely due to greater NDF content (% DM basis) of diets (39.4 vs 36.6%) relative to Xena. Beauchemin et al. (1991) reported an improvement (P = 0.05) in mean ruminal pH in dairy cattle when the NDF content of the diets increased from 29 to 32% (% DM basis). Greater NDF content of diets likely improves ruminal pH by increased rumination and saliva production (Ivan et al. 2005).

There was a tendency (P = 0.08) for heifers fed HIGH silage diets to have a relatively higher minimum rumen pH than those fed LOW silage diets. Russell (1998) reported that dairy cattle fed 90% concentrate had lower rumen pH (6.2 vs 6.9) relative to cows fed forage based diets. In the study of Beauchemin et al. (1991), the NDF content of the diet was increased by

Table 5. 4. Ruminal pH parameters of hiefers fed CDC Cowboy or Xena based barley silage diets at 2 inclusion levels in Studies 1 and 2

	Variety		Level			*P* value		
	CDC Cowboy	Xena	LOW	HIGH	SEM	V	L	V × L
Study 1								
Spot pH	6.52	6.40	6.47	6.45	0.040	0.05	0.79	0.79
In-dwelling ruminal pH probe measurements								
Mean daily ruminal pH	6.44	6.29	6.32	6.41	0.049	0.06	0.28	0.76
Minimum ruminal pH	5.75	5.52	5.56	5.72	0.087	0.02	0.08	0.54
Maximum ruminal pH	6.91	6.86	6.87	6.91	0.038	0.42	0.47	0.53
Ruminal pH parameter 5.8 or lower								
Total duration (min d^{-1})	56.8	166.5	139.7	83.5	30.43	0.01	0.16	0.19
pH area (pH*min)	11.4	31.1	28.8	13.7	8.33	0.12	0.23	0.34
Ruminal pH parameter 5.5 or lower								
Total duration (min d^{-1})	13.7	31.6	34.8	10.5	15.43	0.43	0.29	0.28
pH area (pH*min)	1.30	2.46	2.87	0.90	1.55	0.61	0.39	0.27
Study 2								
Spot pH	6.17	6.12	6.04	6.25	0.05	0.09	< 0.01	< 0.01
In-dwelling ruminal pH probe measurements								
Mean daily ruminal pH	6.04	5.98	5.89	6.13	0.081	0.56	0.06	0.44
Minimum ruminal pH	5.40	5.31	5.29	5.43	0.095	0.50	0.31	0.76
Maximum ruminal pH	6.66	6.59	6.52	6.73	0.061	0.46	0.04	0.56
Ruminal pH parameter 5.8 or lower								
Total duration (min d^{-1})	417.0	464.5	593.5	288.0	96.98	0.73	0.05	0.53
pH area (pH*min)	137.6	158.7	196.0	100.4	46.57	0.75	0.17	0.38
Ruminal pH parameter 5.5 or lower								
Total duration (min d^{-1})	212.3	209.8	298.5	123.5	64.87	0.98	0.08	0.51
pH area (pH*min)	40.5	61.2	61.6	40.1	25.62	0.58	0.56	0.35
Ruminal pH parameter 5.2 or lower								
Total duration (min d^{-1})	45.7	70.1	77.6	38.2	37.73	0.65	0.47	0.42
pH area (pH*min)	5.11	21.8	8.84	18.1	13.21	0.39	0.63	0.33

Note: Barley silage:barley grain ratio is 1:1 for LOW inclusion and 2:1 for HIGH inclusion during Study 1 and 1:17 for LOW and 1:5 for HIGH inclusion diets during Study 2; SEM, pooled standard error of mean; V, barley variety; L, level of inclusion; V × L, variety × level interaction.

increasing the forage:concentrate ratio from 35:65 to 45:55 (% DM basis). An increase in forage proportion in the diet increases physically effective NDF (peNDF). The peNDF is the fraction of fiber that stimulates chewing activity and contributes to the formation of the rumen mat (Yang and Beauchemin 2006). However, increased peNDF content may not always increase rumen pH (Beauchemin 2000; Beauchemin and Yang 2005). These authors reported a poor correlation (R^2 < 0.13) between ruminal pH and dietary fiber measured as either total dietary NDF, forage NDF or peNDF (Beauchemin 2000). It was concluded that factors other than dietary NDF such as DMI, diet fermentability and feeding management practices also influence ruminal pH. Similarly, Allen (1997) reported a poor correlation ($P = 0.27$; $r^2 = 0.01$) between dietary NDF content and ruminal pH in dairy cattle. However, a positive correlation ($P < 0.01$; $r^2 = 0.63$) between forage NDF as a % of DM and ruminal pH was noted.

Heifers fed Xena had a longer ($P = 0.01$) duration under the pH threshold for mild ruminal acidosis (pH 5.8) relative to those fed CDC Cowboy. A longer duration which rumen pH is below 5.8 has been reported to decrease DMI and fiber digestibility (Allen 1997; Beauchemin and McAllister 2008). Beauchemin and McAllister (2008) also reported negative impacts of lower ruminal pH on diet digestibility, feed efficiency and feeding costs in feedlot cattle. Duration under pH 5.8 is considered to be critical for fiber digestion (Rotger et al. 2005), as cellulolytic activity and NDF digestibility are negatively affected as rumen pH drops below this level (Hoover 1986). However, total tract ADF or NDF digestibility was not negatively affected in heifers fed Xena relative to those fed CDC Cowboy silage (Table 5.7). It should be noted that the duration under pH threshold 5.8, although higher for heifers fed Xena than those fed CDC cowboy, was lower than the minimum duration (4 h continuous time period) required for an acidotic bout (Beauchemin and McAllister 2008). These results correspond to the absence

of any negative effect on DMI of steers fed Xena relative to CDC Cowboy in the backgrounding study. Moreover, area under pH 5.8, duration and area under pH 5.5 in the current study were not different among treatments.

Study 2

There was no V × L interaction for any pH related measurements except for spot rumen pH samples (Table 5.4), where heifers fed CDC Cowboy HIGH had greater ($P < 0.01$) mean rumen pH (6.35) relative to those fed Xena HIGH (6.16), Xena LOW (6.08) or CDC Cowboy LOW (6.00) diets (data not shown). Greater mean rumen pH for heifers fed CDC Cowboy HIGH diets corresponds to the greater dietary NDF content (23.2%) relative to those fed Xena HIGH (22.9%), CDC cowboy LOW (19.6%) or Xena LOW (19.4%) diets (data not shown).

HIGH silage diets had relatively greater mean rumen pH than LOW silage diets as measured by in-dwelling pH probes (6.13 vs 5.89; $P = 0.06$). Greater dietary forage NDF (23.1 vs 19.5%) and lower starch (49.6 vs 54.5%) content (% DM basis) in HIGH relative to LOW silage diets likely led to a higher mean rumen pH in cattle fed these diets. Similarly, maximum rumen pH was greater (6.73 vs 6.52) for heifers fed HIGH relative to LOW silage diets ($P = 0.04$). Morine et al. (2014) reported a linear increase in rumen pH of feedlot steers fed finishing diets with increasing concentration of roughage NDF content. These authors reported that the rumen pH increased from 5.48 to 5.80 as forage concentration was increased from 3.5 to 11.4% in corn based finishing diets. Heifers fed HIGH relative to LOW silage diets had a lower ($P = 0.05$) duration (288.0 vs 593.5 min d^{-1}) under pH 5.8. Similarly, there was a trend ($P = 0.08$) for a lower duration (123.5 vs 298.5 min d^{-1}) under pH 5.5 for heifers fed HIGH relative to LOW silage diets. It should be noted that the HIGH silage diets had 10% greater barley silage (14.9 vs

5.0%) and 10% lower barley grain (76.8 vs 86.9%) relative to LOW silage diets. Increased availability of readily fermentable carbohydrates in the rumen (i.e. barley grain vs silage) of LOW silage diets is likely responsible for reduced rumen pH. Heifers did not vary in area under pH 5.8, 5.5 or the duration or area under pH 5.2.

5.4.3 Ruminal Fermentation

Study 1

The effect of variety and level of inclusion of silage in the diet of heifers fed backgrounding diets on ruminal fermentation parameters is presented in Table 5.5. There was no V × L interaction for any of the measured rumen fermentation parameters except for isobutyrate ($P = 0.02$) and ammonia ($P < 0.01$) concentrations. Concentration of acetate, propionate and butyrate were not influenced by treatment. CDC Cowboy HIGH resulted in a relatively greater concentration of isobutyrate (0.93 vs 0.85 mmol L^{-1}) relative to CDC Cowboy LOW. However, heifers fed Xena LOW had greater isobutyrate concentration (0.92 vs 0.84 mmol L^{-1}) relative to Xena HIGH (data not shown). Branched chain volatile fatty acids (BCVFA) such as isobutyrate and isovalerate are produced by the catabolism of dietary branched chain amino acids in the rumen (Allison 1969). Most of the ruminal cellulolytic bacteria require BCVFA for the production of microbial branched chain amino acids and fatty acids (Allison 1969; Zhang et al. 2013). Heifers fed CDC Cowboy had lower ($P = 0.04$) valerate concentration (1.16 vs 1.30 mmol L^{-1}) relative to Xena. Total VFA concentration did not differ among treatments and averaged 102.0 ± 1.41 mmol L^{-1} (mean ± SD). Similarly, A:P ratio averaged 3.04 ± 0.05 mmol L^{-1} (mean ± SD) across diets. Russell (1998) reported that dairy cattle fed 90% concentrate had greater propionate, butyrate, total VFA and lower A:P ratio relative to cows fed 100% forage.

Table 5. 5. Rumen fermentation parameters of heifers fed CDC Cowboy or Xena based barley silage diets at two inclusion levels in Studies 1 and 2

	Variety		Level			*P* value		
	CDC Cowboy	Xena	LOW	HIGH	SEM	V	L	V × L
Study 1								
VFA (mmol L⁻¹)								
Acetate	63.8	65.6	64.5	64.9	1.46	0.34	0.83	0.18
Propionate	21.5	22.4	22.7	21.2	0.77	0.35	0.19	0.73
Butyrate	11.7	11.8	12.0	11.5	0.43	0.92	0.36	0.62
Isobutyrate	0.89	0.88	0.89	0.89	0.022	0.87	0.94	0.02
Valerate	1.16	1.30	1.26	1.20	0.042	0.04	0.32	0.34
Isovalerate	1.41	1.56	1.48	1.48	0.070	0.13	0.97	0.40
Total VFA	100.5	103.5	102.8	101.1	2.07	0.28	0.55	0.43
A:P Ratio[a]	3.01	3.07	2.98	3.10	0.107	0.70	0.45	0.58
Ruminal NH3-N (mg dL⁻¹)	7.72	7.02	7.06	7.67	0.445	0.06	0.11	< 0.01
Study 2								
VFA (mmol L⁻¹)								
Acetate	57.5	58.3	58.3	57.4	1.49	0.71	0.69	0.24
Propionate	32.6	31.3	32.6	31.3	2.18	0.69	0.65	0.36
Butyrate	17.3	15.5	16.1	16.7	1.16	0.28	0.70	0.36
Isobutyrate	0.81	0.82	0.80	0.82	0.049	0.73	0.46	< 0.01
Valerate	1.53	1.58	1.81	1.31	0.134	0.82	0.04	0.88
Isovalerate	1.37	3.19	2.87	1.70	0.719	< 0.01	< 0.01	< 0.01
Total VFA	113.0	108.8	111.3	110.5	2.71	0.28	0.83	0.63
A:P Ratio[a]	1.64	2.19	1.58	2.25	0.23	< 0.01	< 0.01	< 0.01
Ruminal NH3-N (mg dL⁻¹)	5.61	5.42	5.52	5.51	0.874	0.76	1.00	0.40

Note: Barley silage:barley grain ratio is 1:1 for LOW inclusion and 2:1 for HIGH inclusion during Study 1 and 1:17 for LOW and 1:5 for HIGH inclusion diets during Study 2; SEM, pooled standard error of mean; V, barley variety; L, level of inclusion; V × L, variety × level interaction. Values with lowercased letters differ among all treatments ($P < 0.05$).

[a]A:P Ratio = Acetate (A, mmol):Propionate (P, mmol) ratio

Ammonia concentration was greater for CDC Cowboy HIGH (8.6 mg dL^{-1}) relative to CDC Cowboy LOW (6.8 mg dL^{-1}) and Xena HIGH (6.7 mg dL^{-1}) with Xena LOW being intermediate (7.3 mg dL^{-1}). A mean ruminal NH_3-N concentration of 7.4 ± 0.4 mg dL^{-1} (mean ± SD) across treatments indicated that ruminal ammonia concentrations were sufficient to meet the requirements for rumen microbial protein synthesis (Satter and Slyter 1974).

Study 2

As in study 1, there was no significant V × L interaction for any of the measured rumen fermentation parameters except for isobutyrate ($P < 0.01$), isovalerate ($P < 0.01$) and A:P ratio ($P < 0.01$). Concentration of acetate, propionate and butyrate were not influenced by treatment and averaged 57.9 ± 0.56, 32.0 ± 0.87 and 16.4 ± 1.29 mmol L^{-1} (mean ± SD) respectively, across varieties. Heifers fed finishing diets (Study 2) tended to have lower acetate and greater propionate and butyrate concentrations than heifers fed backgrounding diets (Study 1). Bauman et al. (1971) and Russell (1998) reported that cows fed high grain diets had a greater molar percentage of rumen propionate and lower molar percentage of rumen acetate relative to cattle fed roughage diets. Fermentation of starch in high grain diets produces more propionate while fermentation of structural carbohydrates in high forage diets produces more acetate (Dijkstra 1994). Ruminal isobutyrate and isovalerate concentrations showed a V × L interaction. Ruminal isobutyrate concentration of heifers fed CDC Cowboy HIGH (0.93 mmol L^{-1}) and Xena LOW (0.92 mmol L^{-1}) were greater ($P < 0.01$) than those fed Xena HIGH (0.71 mmol L^{-1}) and CDC Cowboy LOW (0.69 mmol L^{-1}) diets. Similarly, heifers fed Xena LOW diets had greater isovalerate concentration (4.73 mmol L^{-1}) relative to heifers fed CDC Cowboy LOW (1.00 mmol L^{-1}) with those fed CDC Cowboy HIGH (1.74 mmol L^{-1}) and Xena HIGH (1.65 mmol L^{-1}) being

intermediate (data not shown). Heifers fed LOW silage diets had greater (P = 0.04) valerate concentration (1.81 vs 1.31 mmol L^{-1}) relative to those fed HIGH silage diets.

Total VFA concentration averaged 110.9 ± 2.97 mmol L^{-1} (mean ± SD) across varieties and was greater than that reported in Study 1. The A:P ratio was influenced by a V × L interaction, where heifers fed CDC Cowboy HIGH (2.26), Xena HIGH (2.25) and Xena LOW (2.14) had a A:P greater than that of heifers fed CDC Cowboy LOW (1.01). The relatively higher A:P ratio in high silage diets is to be expected. For example, Bauman et al. (1971) reported that dairy cattle fed *ad libitum* forage diets had an A:P ratio of 3:1 as compared to those fed high grain diets where this ratio was 1:1. Moreover, these authors also reported greater total VFA concentration (122 vs 101 mmol L^{-1}) for cattle fed high grain as compared to high forage diets. Ruminal NH_3-N concentration averaged 5.5 ± 0.34 mg dL^{-1} (mean ± SD) across varieties (Figure 6; Appendix). Average ruminal NH_3-N concentration was lower than that reported in Study 1. Cows fed high forage vs high concentrate diets have been reported to have greater ruminal NH_3-N concentrations (Agle et al. 2010). These authors reported that greater availability of fermentable carbohydrates for cows fed high grain diets improves microbial utilization of dietary N. Moreover, optimum ruminal NH_3-N requirement depends on ruminal microflora as cellulolytic bacteria require NH_3-N as the major N source while amylolytic bacteria utilize both NH_3-N and AA (Firkins 2010).

5.4.4 Ruminal DM and NDF digestion and flow rate

There was no significant V × L interaction (P > 0.05) for any of the measured ruminal DM or NDF digestibility parameters (Table 5.6). However, there was an effect of level of inclusion in the diet with HIGH silage diets resulting in lower DMI, lower apparent ruminal DM digestion

(kg d^{-1}) and lower apparent DM digestibility (% of DM intake) in heifers as compared to those fed LOW inclusion diets. Improved ruminal DM digestibility of LOW silage diets corresponds to the greater concentrate and lower forage levels in these diets as compared to HIGH silage diets (Table 5.2).

NDF intake (kg d^{-1}), omasal NDF flow (kg d^{-1}) and apparent NDF digestion (kg d^{-1} and % of NDF intake) in the rumen did not vary among treatments (Table 5.6). The NDF intake (kg d^{-1}) during the omasal sampling period closely corresponded to the NDF intake during total tract collection (Table 5.7). The omasal NDF flow (kg d^{-1}) and apparent ruminal NDF digestion (kg d^{-1} and % of NDF intake) values in the present study lie within the range reported by Huhtanen et al. (2010). In a meta-analysis of ruminal digestion of NDF using an omasal sampling techniques in cattle, these authors reported a range of omasal NDF flow from 0.67 - 4.92 kg d^{-1}, ruminal NDF digestion from 1.32 - 6.82 kg d^{-1} and apparent ruminal NDF digestibility from 27.0 - 80.9%. However, ruminal NDF digestion (% of NDF intake) is relatively lower than that reported by Titgemeyer (1997) and Brito et al. (2006) attributed more than 80% of the total tract NDF digestion to ruminal NDF digestion (% of NDF intake). Average ruminal NDF digestion (% of NDF intake) in the present study was 62% of total tract NDF digestibility across diets (Table 5.6). Ruminal NDF digestion (% of NDF intake) has been negatively associated with a greater DMI and faster ruminal outflow (Oba and Allen 2003). However, DMI did not differ during omasal sampling and averaged 11.6 ± 1.2 kg (2.1 % of BW) across treatments. Incomplete recovery of markers and unrepresentative samples could result in an over- or underestimation of ruminal nutrient flow and digestibility. These errors arise due to inappropriate ratios of particulates in samples that do not accurately reflect particle distribution in ruminal digesta (Titgemeyer 1997).

Table 5.6. The effects of feeding diets containing CDC Cowboy or Xena barley silages at two levels of inclusion in backgrounding diets on ruminal DM and NDF digestion and omasal flow in beef heifers

	Variety		Level[a]			*P* value		
Item	CDC Cowboy	Xena	LOW	HIGH	SEM[b]	V	L	V × L
DM								
Intake kg/d	11.3	11.7	12.0	11.0	0.50	0.34	0.05	0.08
Omasal flow, kg/d	9.1	9.0	9.0	9.1	0.28	0.81	0.70	0.17
Apparent digestion, kg/d	2.2	2.9	3.0	2.0	0.28	0.12	0.04	0.83
Apparent digestion, % of DM intake	18.9	23.9	24.7	18.2	2.00	0.11	0.04	0.90
NDF								
Intake kg/d	4.44	4.33	4.26	4.51	0.172	0.66	0.33	0.30
Omasal flow, kg/d	3.15	2.94	2.96	3.12	0.124	0.26	0.37	0.34
Apparent digestion, kg/d	1.29	1.39	1.30	1.38	0.146	0.64	0.69	0.68
Apparent digestion, % of NDF intake	28.7	32.0	30.3	30.4	2.70	0.39	0.98	0.90

Note: V, barley variety; L, level of inclusion; V × L, variety × level interaction.

[a]Barley silage:barley grain ratio is 1:1 for LOW inclusion and 2:1 for HIGH inclusion.

5.4.5 Digestibility

Study 1

There was no V × L interaction for DM or NDF intake, apparent total tract digestibility or digestible energy intake of heifers (Table 5.7). Dry matter intake averaged 11.3 ± 0.5 kg d^{-1} (mean ± SD). However, DMI and DMI as % of BW was numerically greater for heifers fed Xena relative to CDC Cowboy. Nair et al. (2016b) reported numerically greater DMI (8.0 vs 7.7 kg d^{-1}) and DMI as % of BW (2.29 vs 2.22) for steers fed Xena relative to CDC Cowboy in a concurrent backgrounding study. Similarly, heifers fed HIGH silage diets had numerically lower DMI (10.7 vs 11.8 kg d^{-1}) and DMI as % of BW (2.02 vs 2.22) relative to those fed LOW silage diets. Nair et al. (2016b) reported lower ($P < 0.01$) DMI (7.7 vs 8.3 kg d^{-1}) and DMI as % of BW (2.23 vs 2.36) for steers fed similar HIGH relative to LOW silage diets during a 68 d backgrounding study. Failure to see a significant effect of treatment on DMI in the present study may reflect tbe experimental design. The current study was a 4 × 4 Latin square with heifers being fed individually with no competition whereas Nair et al. (2016b) conducted a small pen study with group feeding. Average DMI (kg d^{-1}) in the present study was greater (11.3 ± 0.5 vs 8.0 ± 0.5) than that reported for steers in the concurrent backgrounding study (Nair et al. 2016b). However, it should be noted that the heifers in the present study were heavier (531 ± 46 vs 376 ± 27 kg Mean ± SD) relative to the steers during backgrounding. There was no effect of variety or level of silage on apparent total tract digestibility characteristics of any of the measured nutrients (Table 5.7). It is important to note that while the concentrations of CP and EE were similar across the treatments, levels of ADF and NDF were greater and starch lower for CDC Cowboy and HIGH relative to Xena and LOW silage diets (Table 5.3). Moreover, the varieties did not differ in terms of $NDFD_{30h}$ (Table 5.1).

Table 5. 6. Total tract digestibility coefficients of heifers fed diets containing CDC Cowboy or Xena barley silages at two levels of inclusion in Study 1

	Variety		Level			*P* value		
	CDC Cowboy	Xena	LOW	HIGH	SEM	V	L	V × L
Intake								
DMI, kg d^{-1}	11.1	11.5	11.8	10.7	0.46	0.53	0.13	0.22
DMI, % BW	2.08	2.17	2.22	2.02	0.133	0.55	0.21	0.30
NDF intake, kg d^{-1}	4.35	4.18	4.19	4.34	0.187	0.52	0.60	0.24
NDF intake, % BW	0.83	0.80	0.79	0.83	0.048	0.68	0.54	0.32
Apparent nutrient digestibility coefficient (% DM basis)								
DM	65.5	66.9	66.6	65.8	1.03	0.27	0.57	0.99
OM	66.9	68.6	68.3	67.2	0.98	0.18	0.38	0.87
CP	67.1	67.0	66.4	67.7	1.05	0.95	0.30	0.87
EE	43.9	42.8	43.1	43.6	5.41	0.85	0.94	0.70
NDF	49.4	49.3	48.9	49.8	1.78	0.98	0.68	0.88
ADF	43.9	43.3	43.7	43.5	1.79	0.75	0.93	0.80
Starch	91.6	90.3	91.1	90.8	1.30	0.41	0.85	0.43
DE (Mcal kg^{-1})	2.66	2.75	2.72	2.69	0.032	0.07	0.51	0.78
DE intake (Mcal d^{-1})	27.6	30.1	30.8	26.9	1.275	0.07	<0.01	0.74

Note: Barley silage:barley grain ratio was 1:1 for LOW inclusion and 2:1 for HIGH inclusion; SEM, pooled standard error of mean; V, barley variety; L, level of inclusion; V × L, variety × level interaction; DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fiber; ADF, acid detergent fiber

Digestible energy content (Mcal kg^{-1} DM) averaged 2.71 ± 0.04 Mcal (Mean ± SD) across treatments. There was a tendency ($P = 0.07$) for a lower DE for diets containing CDC Cowboy relative to Xena. Similarly, heifers fed CDC Cowboy showed a tendency ($P = 0.07$) for lower DE intake (Mcal d^{-1}) relative to those fed Xena. Moreover, heifers fed HIGH silage diets had lower ($P < 0.01$) DE intake (Mcal d^{-1}) relative to those fed LOW silage diets. The lower DE intake by heifers fed CDC Cowboy and HIGH silage diets is likely due to the lower starch content in CDC Cowboy relative to Xena (Table 5.1) and in the HIGH silage diet (Table 5.3), as well as due to greater NDF intake and numerically lower DMI. These results help to explain the observations of Nair et al. (2016b) who reported a lower ($P < 0.01$) NE_g intake (Mcal d^{-1}) for steers fed CDC Cowboy and HIGH silage diets relative to those fed Xena and LOW silage diets, a concurrent backgrounding study. These authors concluded that the lower DM and NE_g intake by steers fed CDC Cowboy and HIGH silage diets led to poorer backgrounding performance.

Study 2

As in Study 1, there was no significant V × L interaction on DM and NDF intake, apparent total tract digestibility or digestible energy intake of heifers fed finishing diets formulated with either CDC Cowboy or Xena at either inclusion level (Table 5.8). Dry matter intake of heifers averaged 12.2 ± 0.57 kg d^{-1} (mean ± SD) across treatments. There was a tendency ($P = 0.10$) for heifers fed HIGH silage diets to have greater DMI as a % of BW (2.23 vs 2.04) relative to those fed LOW silage diets. Moreover, heifers fed HIGH silage diets had greater ($P < 0.01$) NDF intake (kg d^{-1} and % BW basis) relative to those fed LOW silage diets. These results are similar to that reported by Nair et al. (2016b) in the concurrent finishing study. However, heifers in the present study had relatively greater DMI (12.2 vs 10.1kg d^{-1}) and NDF intake (2.6 vs 2.1 kg d^{-1}) than steers in the feedlot study. As previously noted, heifers in this study were heavier (570 ± 54 vs

508 ± 8 kg) as compared to steers in the finishing study. Relatively greater DMI and DMI as % of BW for heifers fed HIGH relative to LOW silage diets is due to greater NDF content. Allen (2000) also reported that as DMI increases with increasing NDF content when energy as opposed to gut fill limits intake.

There was no effect of variety or level of inclusion on apparent total tract digestibility characteristics of any measured nutrients except for a tendency ($P = 0.06$) for greater ADF digestibility for heifers fed HIGH vs LOW silage diets (Table 5.8). The tendency for greater ADF digestibility for HIGH relative to LOW silage diets is likely due to the greater cell-wall fraction in the diet and a rumen pH that was more favorable for ruminal fiber degradation (Tables 5.3, 5.4). Daily average rumen pH of HIGH silage diets tended to be ($P = 0.06$) greater than that of LOW silage diets. Similarly, the duration of rumen pH under pH 5.8 ($P = 0.05$) and 5.5 ($P = 0.08$) was lower for heifers fed HIGH relative to LOW silage diets. A greater rumen pH for heifers fed HIGH silage diets resulted in improved rumen degradation of forage cell walls. Moreover, numerically greater ruminal ammonia concentration of heifers fed CDC Cowboy and HIGH silage diets relative to those fed Xena and LOW silage diets likely improved cell wall digestion, as cellulolytic bacteria require NH_3-N as the major N source for microbial protein synthesis (Firkins 2010).

Digestible energy content (Mcal kg^{-1} DM) averaged 3.04 ± 0.03 Mcal (Mean ± SD) across treatments. Heifers fed HIGH silage diets had numerically greater (36.0 vs 31.7 Mcal d^{-1}) DE intake relative to those fed LOW silage diets. Greater DE intake reflects the numerically greater DMI ($P = 0.12$) of heifers fed HIGH relative to LOW silage diets. Similar observations

Table 5. 7. Total tract digestibility coefficients of heifers fed diets containing CDC Cowboy or Xena barley silages at two levels of inclusion in Study 2

	Variety		Level			*P* value		
	CDC Cowboy	Xena	LOW	HIGH	SEM	V	L	V × L
Intake								
DMI, kg d^{-1}	12.2	12.1	11.5	12.9	0.59	0.89	0.12	0.91
DMI, % BW	2.15	2.12	2.04	2.23	0.077	0.77	0.10	0.91
NDF intake, kg d^{-1}	2.63	2.56	2.24b	2.96a	0.129	0.71	<0.01	0.83
NDF intake, % BW	0.46	0.45	0.40b	0.51a	0.017	0.57	<0.01	0.98
Apparent nutrient digestibility coefficient (% DM basis)								
DM	76.1	76.2	77.2	75.1	1.77	0.95	0.28	0.88
OM	77.5	77.7	78.7	76.5	1.80	0.91	0.25	0.84
CP	72.7	71.8	72.8	71.7	2.24	0.72	0.64	0.96
EE	43.6	46.0	45.5	44.1	3.69	0.58	0.75	0.79
NDF	51.8	49.7	48.6	52.9	2.13	0.42	0.11	0.42
ADF	43.0	40.1	38.1	44.9	2.76	0.38	0.06	0.61
Starch	93.8	93.7	94.5	93.0	1.80	0.95	0.43	0.83
DE (Mcal kg^{-1})	3.03	3.04	3.07	3.00	0.073	0.97	0.42	0.78
DE intake (Mcal d^{-1})	34.4	33.3	31.7	36.0	1.93	0.69	0.14	0.78

Note: Barley silage:barley grain ratio was 1:17 for LOW and 1:5 for HIGH inclusion diets; SEM, pooled standard error of mean; V, barley variety; L, level of inclusion; V × L, variety × level interaction; DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fiber; ADF, acid detergent fiber

were also made by Nair et al. (2016b) who reported a higher ($P < 0.01$) NE_g intake (Mcal d^{-1}) for steers fed HIGH as compared to those fed LOW silage diets in a concurrent finishing feedlot study.

5.4.6 N balance

Study 1

There was no variety or V × L interaction *(P* > 0.05) for any of the measured N balance parameters (Table 5.9). Total fecal and urinary output averaged 3.6 ± 0.4 kg DM d^{-1} and 12.6 ± 1.2 kg d^{-1} respectively, across treatments. Heifers fed LOW relative to HIGH silage diets had greater ($P = 0.03$) total N intake (g d^{-1}). As the CP content of the diets were similar (13.6 ± 0.05%) across treatments, greater daily N intake of heifers fed LOW silage diets corresponds to their higher DMI (11.8 vs 10.7 kg d^{-1}) as compared to heifers fed HIGH silage diets (Table 5.8). However, total N excretion (g d^{-1}) was similar across treatments and averaged 176.0 ± 26.8 g d^{-1}. Fecal N was influenced by silage inclusion level ($P = 0.02$) with heifers fed LOW silage diets having greater fecal N levels relative to those fed HIGH silage diets. Greater fecal N output for heifers fed LOW silage diets reflects their greater DMI and numerically greater fecal output (3.76 vs 3.43 kg d^{-1}). Fecal and urinary N excretion as a % of total N excreted showed a trend ($P = 0.09$) for greater fecal (45.1 vs. 40.9%) and lower urinary (54.9 vs 59.1%) N excretion in heifers fed LOW vs HIGH silage diets.

Apparent total nitrogen retained ranged from 41.5 to 63.1 g d^{-1}. Moreover, heifers fed LOW silage diets had greater ($P = 0.04$) apparent total N retained relative to those fed HIGH

Table 5. 8. Effect of feeding CDC Cowboy or Xena barley silages in diets of heifers at two levels of inclusion on nitrogen (N) balance in Studies 1 and 2

	Variety		Level			*P* value		
	CDC Cowboy	Xena	LOW	HIGH	SEM	V	L	V × L
Study 1								
Fecal output, (kg DM d^{-1})	3.58	3.62	3.76	3.43	0.152	0.87	0.15	0.90
Urine output, (kg d^{-1})	12.2	13.1	13.0	12.4	0.31	0.11	0.29	0.62
Nitrogen (g d^{-1})								
Total N intake	228.1	239.8	247.5	220.4	7.63	0.30	0.03	0.69
Total N excreted	167.2	184.8	185.1	166.9	8.00	0.26	0.24	0.90
Fecal N	75.2	79.0	83.1	71.1	3.15	0.40	0.02	0.71
% of total N excreted	43.0	43.0	45.1	40.9	1.58	0.98	0.09	0.59
Urinary N	99.7	105.7	102.0	103.5	6.06	0.52	0.86	0.39
% of total N excreted	57.0	57.0	54.9	59.1	1.58	0.98	0.09	0.59
Apparent total N retained	50.1	54.4	63.1	41.5	9.10	0.64	0.04	0.28
N retained as a % of intake	22.1	22.6	25.2	19.4	3.27	0.88	0.12	0.19
Study 2								
Fecal output, (kg DM d^{-1})	2.68	2.62	2.45	2.84	0.304	0.82	0.15	0.64
Urine output, (kg d^{-1})	13.6	13.2	12.6	14.2	0.89	0.78	0.24	0.21
Nitrogen (g d^{-1})								
Total N intake	240.3	231.9	225.8	246.3	15.36	0.62	0.25	0.77
Total N excreted	169.1	151.1	143.4	176.8	7.11	0.10	<0.01	0.80
Fecal N	65.5	66.2	62.7	69.1	7.16	0.91	0.32	0.81
% of total N excreted	39.5	44.3	42.2	41.5	3.45	0.35	0.89	0.85
Urinary N	102.0	84.6	83	103.5	6.61	0.09	0.05	0.92
% of total N excreted	60.5	55.7	57.8	58.5	3.45	0.35	0.89	0.85
Apparent total N retained	76.6	83.5	78.9	81.3	12.43	0.70	0.89	0.82
N retained as a % of intake	29.9	34.7	33.2	31.5	3.92	0.40	0.76	0.75

Note: Barley silage:barley grain ratio is 1:1 for LOW inclusion and 2:1 for HIGH inclusion during Study 1 and 1:17 for LOW and 1:5 for HIGH inclusion diets during Study 2; SEM, pooled standard error of mean; V, barley variety; L, level of inclusion; V × L, variety × level interaction; DM, dry matter; OM, organic matter; CP, crude protein; EE, ether extract; NDF, neutral detergent fiber; ADF, acid detergent fiber

silage diets. These observations support the findings of Nair et al (2016b) who reported greater end of backgrounding body weight and ADG for steers fed LOW relative to HIGH silage diets in a concurrent feedlot study.

Study 2

As in Study 1, there was no significant V × L interaction for any of the measured N balance parameters for heifers fed either CDC Cowboy or Xena at two inclusion levels in the finishing diets (Table 5.9). Total fecal and urinary output averaged 2.7 ± 0.7 kg DM d^{-1} and 13.4 ± 2.6 kg d^{-1} respectively, across treatments. Similarly, total N intake averaged 240.2 ± 40.4 kg d^{-1} across treatments. Heifers fed CDC Cowboy tended ($P = 0.10$) to excrete more N e relative to those fed Xena. Heifers fed CDC Cowboy diets also tended ($P = 0.09$) to exhibit higher urinary N excretion relative to those fed Xena. Moreover, heifers fed HIGH silage diets had greater total ($P < 0.01$) and urinary ($P = 0.05$) N excretion relative to those fed LOW silage diets. Apparent N retained averaged 80.1 ± 31.7 g d^{-1} (Mean ± SD) across treatments. Average apparent total N retained in Study 2 was greater (80.1 ± 31.7 vs 50.2 ± 17.7 g d^{-1}; Mean ± SD) than in Study 1. The greater apparent total N retention in Study 2 likely reflects improved total tract CP digestibility (72.2 ± 4.6 vs 67.1 ± 2.3 %; Mean ± SD). However, the retained N values in the present study are somewhat overestimated than would be predicted based on observed lean tissue deposition. Walter et al. (2012) reported that apparent N retention of 48 - 86 g d^{-1} corresponds to gain in excess of 2 kg d^{-1}. Volatilization of fecal and urinary N during total collection and sample processing may overestimate retained N (Kohn et al. 2005). However, in the present study, concentrated HCl was added to urine collection vessels to minimize volatilization of urinary N during total collection.

5.5 Conclusion

These results show that barley grown for silage has minimal impact on total tract nutrient utilization in heifers fed either backgrounding or finishing diets. However, varieties such as CDC cowboy and HIGH silage inclusion levels that increase NDF intake can lead to lower DE intake and potentially poorer average daily gains in backgrounding cattle. When included in backgrounding diets with higher overall forage levels, CDC Cowboy and HIGH silage diets with greater NDF content lead to improved ruminal pH parameters relative to diets with lower NDF levels. Greater apparent N retained in heifers fed Xena and LOW silage diets reflects the higher DE intake with these diets. In finishing diets where forage inclusion levels were minimal, barley variety had little influence on digestibility or rumen fermentation parameters. However, HIGH silage inclusions can lead to improved rumen pH conditions that facilitate fiber digestibility which in turn lead to improved DMI and compensatory gain in finishing steers.

In relation to the overall hypothesis of this research, this study showed that barley variety while influencing NDF content of the diet, had relatively minimal impact on NDF digestibility. This result reflects the fact that NDFD did not differ between the three varieties in this study, likely due to the fact that all varieties were treated identically from an agronomic perspective. This is in contrast to the results of Chapter 3 where commercial samples showed clear differences in NDFD between varieties particularly between CDC Cowboy and Xena. While samples in Chapter 3 were harvested by producers at mid-dough, differences in maturity may have existed that influenced NDFD in these samples. It is possible that a variety × maturity at harvest interaction exists that influences not only nutrient content but also NDFD between varieties. The following chapter will explore the nature of this interaction, if present.

6.0 Effect of Variety and Stage of Maturity at Harvest on Nutrient and Neutral Detergent Fiber Digestibility of Forage Barley Grown in Western Canada

6.1 Abstract

This study evaluated the effect of variety (V; CDC Cowboy, CDC Copeland and Xena) and stage of harvest maturity (M; milk, early-, mid- and hard-dough) on nutrient and NDF digestibility (NDFD) characteristics of barley forage using a randomized complete block design with 3 × 4 factorial treatment arrangement. Barley varieties had similar CP, but CDC Cowboy had greater ($P < 0.01$) ADF, NDF and lignin and lower ($P < 0.01$) TDN content relative to Xena. Starch content of CDC Cowboy was lower ($P < 0.01$) than Xena at all maturities with CDC Copeland intermediate at early- and mid-dough stages. Crude protein, ADF, NDF and lignin content decreased ($P < 0.01$), while TDN content increased ($P < 0.01$) with advancing maturity. Xena had greater ($P < 0.01$) $NDFD_{6h}$ at milk, mid- and hard-dough than CDC Cowboy with CDC Copeland intermediate at mid-dough. However, CDC Cowboy had greater ($P < 0.01$) $NDFD_{30h}$ at early-dough than Xena and greater $NDFD_{30h}$ at hard-dough than CDC Copeland. Xena had the lowest ($P < 0.01$) $INDF_{288h}$ relative to CDC Copeland. These results indicate that to optimize $NDFD_{30h}$, variety should be considered when deciding the optimal timing of harvest.

Key words: barley forage, variety, stage of maturity, NDFD

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6.2 Introduction

Feedlot and dairy operations in western Canada primarily rely on whole-crop barley (*Hordeum vulgare* L.) as the major forage source for silage and extended winter grazing systems because of its nutritional and ensiling characteristics (Kaulbars and King 2004), and its short growing season being suitable for the northern Prairies (McAllister et al. 1995; Juskiw et al. 2000). Nair et al. (2016a) reported that barley varieties commercially harvested and ensiled at mid-dough varied in 30-h NDF digestibility ($NDFD_{30h}$), as determined by the Daisy^{II} *in vitro* system, and indigestible NDF ($INDF_{288h}$) content. These authors reported that the barley variety CDC Cowboy had the greatest $NDFD_{30h}$ and the lowest $INDF_{288h}$ content, relative to CDC Copeland and Xena. However, subsequent studies (Nair et al. 2016b; Preston et al. 2016a, 2016b) using these same barley varieties grown in two geographical locations and harvested for silage at mid-dough did not report any variety differences in $NDFD_{30h}$. Differences between these studies include the fact that in the work of Nair et al. (2016a), the silage samples were collected from commercial beef and dairy operations where barley for silage was estimated to be harvested at mid-dough as determined by visual evaluation by individual producers. In contrast, for the work of Nair et al. (2016b) and Preston et al. (2016a, b), the three varieties were all seeded and managed similarly and harvested on the same date at each research centre. Thus, differences in the relative maturity of these varieties between studies may have affected the digestibility results.

Maturity at harvest has a major influence on quality and nutritional value of whole-crop barley for silage (Acosta et al. 1991; Borowiec et al. 1998). These authors also reported that total tract digestibility of NDF decreased as maturity of barley silage increased from boot to mid-dough. Barley is generally harvested at or beforemid-dough stage in western Canada, balancing DM yield and nutrient quality (Bergen 1991; Kaulbars and King 2004). However, Rosser et al.

(2013) reported that the effective degradable DM (EDDM) yield of barley (cv. CDC Cowboy) increased as crop maturity advanced from boot to the mature stage. These authors suggested that harvesting whole-crop cereals at hard-dough and mature stages for swath grazing may increase the yield of EDDM. However, the effect of maturity of barley varieties at harvest on forage production and $NDFD_{30h}$ has not been evaluated. The objectives of this study were to determine how $NDFD_{30h}$ was affected by variety and stage of maturity when barley was seeded, managed and harvested from replicate plots in a similar manner over multiple years. This approach assessed the potential of using nutrient parameters such as $NDFD_{30h}$ as a criterion for selecting an appropriate barley variety for forage production for beef and dairy producers in western Canada.

6.3 Materials and Methods

6.3.1 Agronomic Practices and Sampling

The study was conducted on non-irrigated land (52º09'N 106º33'W, 500 m elevation) at the Kernen Crop Research Farm of the University of Saskatchewan (Saskatoon, SK) over 2 crop years (2014 and 2015). Seed for CDC Cowboy and CDC Copeland were sourced from the Breeder Seed Unit at the Kernen Crop Research Farm (Saskatoon, SK) while seed for Xena was sourced from Crop Production Services (Regina, SK). Each variety was seeded in three adjacent plots (90-cm apart) with each plot subdivided into 3 subplots (50-cm apart) measuring 1.2 m × 3.6 m for a total of 3 replicates for each variety in both crop years. Seeds were pre-treated with Raxil® WW (Bayer CropScience Inc. Calgary, AB) containing Raxil® MD fungicide and Stress Shield® for cereals at a rate of 3 ml kg^{-1} and 0.3 ml kg^{-1} of barley, respectively. Plots were seeded at a rate of 1,400 seeds per plot using a custom seeder with 5 rows spaced 20-cm apart.

Fertilizer (28-23-00) was applied with the seeds at a rate of 55.6 kg ha^{-1}. The herbicide Buctril M (Bayer CropScience Inc. Calgary, AB) was applied at a rate of 692 ml ha^{-1} for post-emergence control of annual and broad-leaf weeds. Whole crop barley samples from each of the replicate plots were collected in both crop years at milk, early-, mid- and hard-dough stages of maturity as determined by visual evaluation as per Zadoks growth scale (Zadoks et al. 1974). At each sampling stage, whole plant barley was hand clipped to a stubble height of 10-cm. Samples of each variety were taken the same day from across the sub-plots for each variety at each stage of maturity. Whole plant barley was cut into 30-cm long sections for drying. Environmental conditions including maximum, minimum and average temperature and precipitation data were collected during both crop years from the weather station at the Kernen Crop Research Farm, University of Saskatchewan.

6.3.2 *In vitro* Incubation (Daisy^{II} System)

A total of 72 samples representing the 3 barley varieties (CDC Cowboy, CDC Copeland and Xena) from 3 replicated plots harvested at 4 different stages of maturity (milk, early-, mid- and hard-dough) over 2 crop years were used for the *in vitro* incubation. The $NDFD_{6h}$ and $NDFD_{30h}$ were measured using the Daisy^{II} system as described by Damiran et al. (2008) and Nair et al. (2016a). Briefly, samples were weighed (0.5 g) into acetone rinsed Ankom F57 filter bags (5.0 × 5.5-cm., Ankom Technology Corporation, Fairport, NY) and heat sealed. There were 2 runs each for both the 6 h and 30 h incubations with four replicates of each sample per run. Four Daisy^{II} incubators each with four glass fermentation jars placed on rotating racks within the cabinet were used for each run. Each jar had a plastic separation panel with holes and lids with gas relief valves. Each Daisy^{II} incubator contained all 72 samples, with incubators maintained at 39.5 ± 0.5ºC. Each jar contained 18 randomly allocated samples, two standards (AAFCO standard 1090;

average NDF content of 39.6% DM) and two blanks. Ruminal fluid was collected from three ruminally cannulated beef heifers fed a 85:15 barley silage:concentrate (% DM basis) diet *ad libitum*. Buffer solution (1600 ml; comprising of 5:1 mixture of solution A: KH_2PO_4, $MgSO_4 \cdot 7H_2O$, NaCl, $CaCl_2 \bullet 2H_2O$, urea and solution B: Na_2CO_3 and $Na_2S \bullet 9H_2O$) and ruminal fluid (400 ml) were both added to each jar, purged with CO_2 and placed into the incubators. At the completion of incubation, the jars were drained and the filter bags were rinsed with cold water until the rinsed water was clear. After rinsing, the bags were placed in an Ankom^{200} fiber analyzer for determination of NDF.

6.3.3 Indigestible NDF

Eight ruminally cannulated beef heifers (497 ± 15 kg; Mean ± SD) were used for the determination of $INDF_{288h}$ by the *in situ* method. Heifers were housed at the Livestock Research Building at the University of Saskatchewan in individual indoor pens with a floor space of 9 m^2. Each pen was equipped with a feeder, automatic water bowl and rubber floor mat. Heifers were fed a 85:15 barley silage:concentrate (% DM basis) diet twice daily for *ad libitum* intake throughout the study. Diets were formulated to meet or exceed the NRC (2000) requirement for CP, energy, minerals and fat-soluble vitamins for backgrounding beef heifers. All heifers were cared for as per the guidelines of Canadian Council on Animal Care (CCAC 2009). Monensin sodium was provided in a vitamin-mineral pellet to achieve 33 mg kg^{-1} (DM) in the diet. Calcium:phosphorus was formulated for 2:1 ratio.

For each forage sample, 3 g was weighed in triplicate into 5 × 10-cm size *in situ* bags (6 µm pore size, part no. 07 – 6/5, Sefar America Inc., Depew, NY). In total, there were 216 bags comprised of three bags each for all 3 varieties from triplicate plots harvested at 4 different stages of maturity over 2 years. Bags were assigned randomly to each heifer. Sample bags were placed

in a laundry bag with a weight to keep the samples immersed and positioned in the ventral sac of the rumen and incubated for 288 h (Huhtanen et al. 1994). Total number of bags incubated in the rumen did not exceed 27 per heifer.

After incubation, bags were removed from the rumen and rinsed in cold water until the rinse water was clear. After rinsing, the bags were soaked in cold water for 30 min to cease all microbial activities. Bags were then dried at 55ºC for 48 h. After drying, the weight of the bag with residue was recorded.

6.3.4 Nutrient Analysis

All barley forage samples were dried in a forced-air oven at 55ºC for 72 h. After drying, samples were ground to pass through a 1-mm screen (Christy & Norris mill 8" Lab mill, Christy Turner Ltd, Chemsford, UK). Samples were analyzed for detailed nutrient composition using a Foss NIRSystems 5000 (NIR Systems, Inc., Silver Spring, MD) at Cumberland Valley Analytical Services (CVAS, Hagerstown, MD). Samples were analyzed for CP (standard error of calibration (SEC) = 0.36, regression coefficient (R^2) = 0.98), EE (SEC = 0.41, R^2 = 0.81), ADF (SEC = 0.83, R^2 = 0.97), lignin (SEC = 0.22, R^2 = 0.90), starch (SEC = 0.93, R^2 = 0.99), ash (SEC = 0.66, R^2 = 0.91), sugar (SEC = 0.78, R^2 = 0.91), ADICP (SEC = 0.13, R^2 = 0.69), NDICP (SEC = 0.17, R^2 = 0.80) and soluble protein (SEC = 0.44, R^2 = 0.97). The NDF of forage samples and residues after Daisy^{II} and ruminal incubation for $INDF_{288h}$ were analyzed by wet chemistry with the addition of amylase and sodium sulfite (Van Soest et al. 1991).

6.3.5 Calculations and Statistical Analysis

Field data including maximum, minimum and mean temperature were calculated as average temperature from seeding to maturity at harvest. Precipitation data were calculated as the total precipitation from seeding to maturity at harvest. Non-fiber carbohydrate (NFC) was calculated as

NFC % = 100 – (CP % + Fat % + Ash % + NDF % - NDICP %; Hall 2015) where NDICP is neutral detergent fiber insoluble crude protein. Nonstructural carbohydrate content (NSC) was calculated as sum of sugars, starch, organic acids and fructans (NRC 2001). Total digestible nutrient (TDN) was calculated as per Weiss summative equation (Weiss 1998). The NDFD (6 and 30 h; % NDF) was calculated as NDFD (% NDF) = (NDF in feed – NDF in residue after 6 or 30 h *in vitro* incubation) ÷ NDF in feed. Indigestible NDF ($INDF_{288h}$) was calculated as $INDF_{288h}$ = [NDF_{288h} ÷ NDF] ×100 where $INDF_{288h}$ is the total indigestible NDF fraction (% NDF); NDF_{288h} is the amount of NDF remaining in the bag after 288 h of incubation (g) and NDF is the amount of NDF in the bag before ruminal incubation (g). Potentially digestible NDF (DNDF, %) was calculated as (100 – $INDF_{288h}$ %). The NDFD (6 and 30 h; % DNDF) was calculated as NDFD (% DNDF) = (NDF in feed – NDF in residue after 6 or 30 h *in vitro* incubation) ÷ DNDF in feed.

The mixed model procedure of SAS (version 9.4; SAS Institute Inc., Cary, NC) with subplot as the experimental unit was used to analyze the chemical composition, NDFD and $INDF_{288h}$ content of the 3 barley varieties harvested at 4 different stages of maturity. As the experiment was designed as a randomized complete block design with a 3 × 4 factorial arrangement of treatments, effects of variety (V), stage of maturity (M) and variety × maturity interaction (V × M) were included in the model. Year was used as random blocking factor. The slice option was used to assess the significance at each level of interaction when V × M was significant. Denominator degrees of freedom were determined using the Kenward-Roger option. Mean separation was done by Tukey's test. Significant differences and trends were declared at $P \leq 0.05$ and $0.05 < P \leq 0.10$, respectively.

6.4 Results and Discussion

The intent of the study was to determine the effects of variety and stage of maturity on nutrient content and on *in vitro* / *in vivo* NDFD of barley forage. Previous work with corn (Oba and Allen 1999) and barley (Oba and Swift 2014; Nair et al. 2016a) silage has shown that variety differences occur in the rate and extent of NDFD and that selection for higher NDFD silage varieties can increase DMI and milk yield (Oba and Allen 1999). However, no studies have evaluated the effects of changes in maturity on $NDFD_{30h}$ of different barley varieties. Characterizing this parameter could provide producers with an indicator to select barley varieties for green feed or silage based on their degree of digestibility.

Barley green feed as opposed to silage was used as the model for this research. It is acknowledged that direct extrapolation of digestibility from green feed to silage may not be possible due to the impacts of fermentation during ensiling on whole crop digestibility. However, the use of green feed allows us to study both the effects of variety and advancing maturity on $NDFD_{30h}$. The major differences between barley green feed and silage likely lie in the reduction in water soluble carbohydrate (WSC) and increase in soluble CP content during ensiling as protein is converted into NPN (Kaulbars and King 2004). However, NPN content of green feed can also increase during drying, thus the difference in terms of NPN content between green feed and silage is minimal (Nadeau 2007).

Environmental data including average temperature and precipitation during the study are presented in Table 6.1. There was minimum variation in temperature between stages of maturity in both study years. However, the cumulative precipitation in year 2 was much lower than in year 1 (40.2 vs 222.0 respectively; Table 6.1). In the present study, average growing degree days

Table 6. 1. Environmental conditions during plant growth for the three barley varieties for each stage of maturity over two crop years

Stage of maturity	Maximum temperature, °C		Minimum temperature, °C		Mean temperature, °C		Cumulative precipitation		Growing degree days[a]	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Milk	21.5 ± 3.97	23.7 ± 5.21	10.4 ± 3.46	9.5 ± 5.06	16.0 ± 3.16	16.6 ± 4.66	188.4	29.8	679.1	682.7
Early-dough	21.9 ± 3.99	23.7 ± 5.09	10.8 ± 3.41	9.8 ± 5.00	16.4 ± 3.20	16.8 ± 4.56	221.4	39.4	829.7	765.2
Mid-dough	22.1 ± 4.04	23.9 ± 5.09	11.0 ± 3.50	10.0 ± 4.99	16.6 ± 3.30	17.0 ± 4.58	221.4	40.2	879.5	814.0
Hard-dough	22.2 ± 4.01	24.1 ± 5.07	11.1 ± 3.47	10.2 ± 4.95	16.7 ± 3.29	17.1 ± 4.56	222.0	40.2	933.1	861.4

Note: Data derived from the University of Saskatchewan Kernen Crop Research Farm weather station. http://www.usask.ca/weather/kfarm/data/?C=M;O=D

[a]Calculated as (maximum temperature + minimum temperature) ÷ 2 - base temperature which is 5°C

(GDD) for the milk (680.9 ± 2.53 (Mean ± SD) and hard-dough (897.3 ± 50.64 (Mean ± SD) stages of maturity at harvest were similar to that of Rosser et al. (2013) who reported 710 and 940 GDD for late milk and hard-dough stages of CDC Cowboy, respectively. The GDD is a measure of heat accumulation for forages in a growing season and is calculated as the average of the day's maximum and minimum temperature minus the base temperature (5ºC; Bauer et al. 2009).

Detailed nutrient composition of barley forage as affected by variety and stage of maturity at harvest are presented in Tables 6.2 through 6.5. The V × M interaction was not significant ($P > 0.05$) for most of the measured nutrient components, except for starch, soluble protein (SP) and ethanol soluble carbohydrate (ESC) content. This indicates that changes in the concentration of most nutrients were similar among varieties. Maturity at harvest influenced ($P < 0.01$) all the measured nutrient components except for EE ($P > 0.05$) which averaged 2.3 ± 0.22 (Mean ± SD) across all maturities (Table 6.2). Variety had an effect on EE concentration with CDC Cowboy having a lower ($P < 0.01$) EE content relative to CDC Copeland and Xena even though the magnitude of this difference was minimal. As expected, DM content of the varieties increased ($P < 0.01$) with advancing maturity. Average DM content across the three varieties at the 4 stages of maturity was similar to that reported in the literature for barley green feed (Nadeau 2007; Rosser et al. 2013). Ash content of CDC Cowboy was greater ($P < 0.01$) relative to CDC Copeland and Xena. Moreover, ash content decreased ($P < 0.01$) with advancing barley maturity.

Crude protein content averaged 10.2 ± 0.97 % (Mean ± SD; % DM basis) across varieties (Table 6.3). When expressed as a % of CP basis, soluble protein (SP) showed a V × M

Table 6. 2. Effect of barley variety and stage of maturity at harvest on DM, EE and ash content

	Variety			Stage of maturity at harvest							
									P value[b]		
	CDC Cowboy	CDC Copeland	Xena	Milk	Early-dough	Mid-dough	Hard-dough	SEM	V	M	V × M
DM	33.9	35.0	35.0	26.7d	34.2c	37.8b	39.9a	0.52	0.15	< 0.01	0.66
Item (% DM basis unless otherwise stated)											
EE	2.15b	2.43a	2.30a	2.31	2.31	2.31	2.24	0.074	< 0.01	0.65	0.95
Ash	9.10a	8.29b	8.49b	9.48a	8.52b	8.36bc	8.13c	0.170	< 0.01	< 0.01	0.86

Note: DM, dry matter; EE, ether extract; V, variety of barley; M, maturity at harvest; V × M, interaction between variety and maturity. Means without a common lower cased letter differ ($P < 0.05$)

Table 6. 3. Effect of variety and stage of maturity at harvest on protein fractions of common barley varieties grown for silage

	Variety			Stage of maturity at harvest					*P* value[b]		
	CDC Cowboy	CDC Copeland	Xena	Milk	Early-dough	Mid-dough	Hard-dough	SEM	V	M	V × M
Item (% DM basis unless otherwise stated)											
CP	10.1	10.2	10.4	11.1a	10.2b	10.0b	9.6b	0.50	0.20	< 0.01	0.96
SP	4.67	4.62	4.72	5.12a	4.69b	4.53bc	4.33c	0.448	0.58	< 0.01	0.74
SP, % of CP	46.0	45.3	45.0	46.1	45.8	45.1	44.7	2.17	< 0.01	< 0.01	0.03
ADICP	1.00a	0.96c	0.98b	0.93d	0.96c	0.99b	1.02a	0.035	< 0.01	< 0.01	0.81
ADICP, % of CP	10.0a	9.60ab	9.42b	8.51c	9.55b	9.94b	10.7a	0.838	0.02	< 0.01	0.84
NDICP	1.85a	1.76b	1.78b	2.11a	1.75b	1.70bc	1.64c	0.027	< 0.01	< 0.01	0.90
NDICP, % of CP	18.4a	17.5b	17.0c	19.2a	17.3b	17.0b	17.1b	1.04	< 0.01	< 0.01	0.16

Note: CP, crude protein; SP, soluble protein; ADICP, acid detergent insoluble crude protein; NDICP, neutral detergent insoluble crude protein; V, variety of barley; M, maturity at harvest; V × M, interaction between variety and maturity. Means without a common lower cased letter differ ($P < 0.05$)

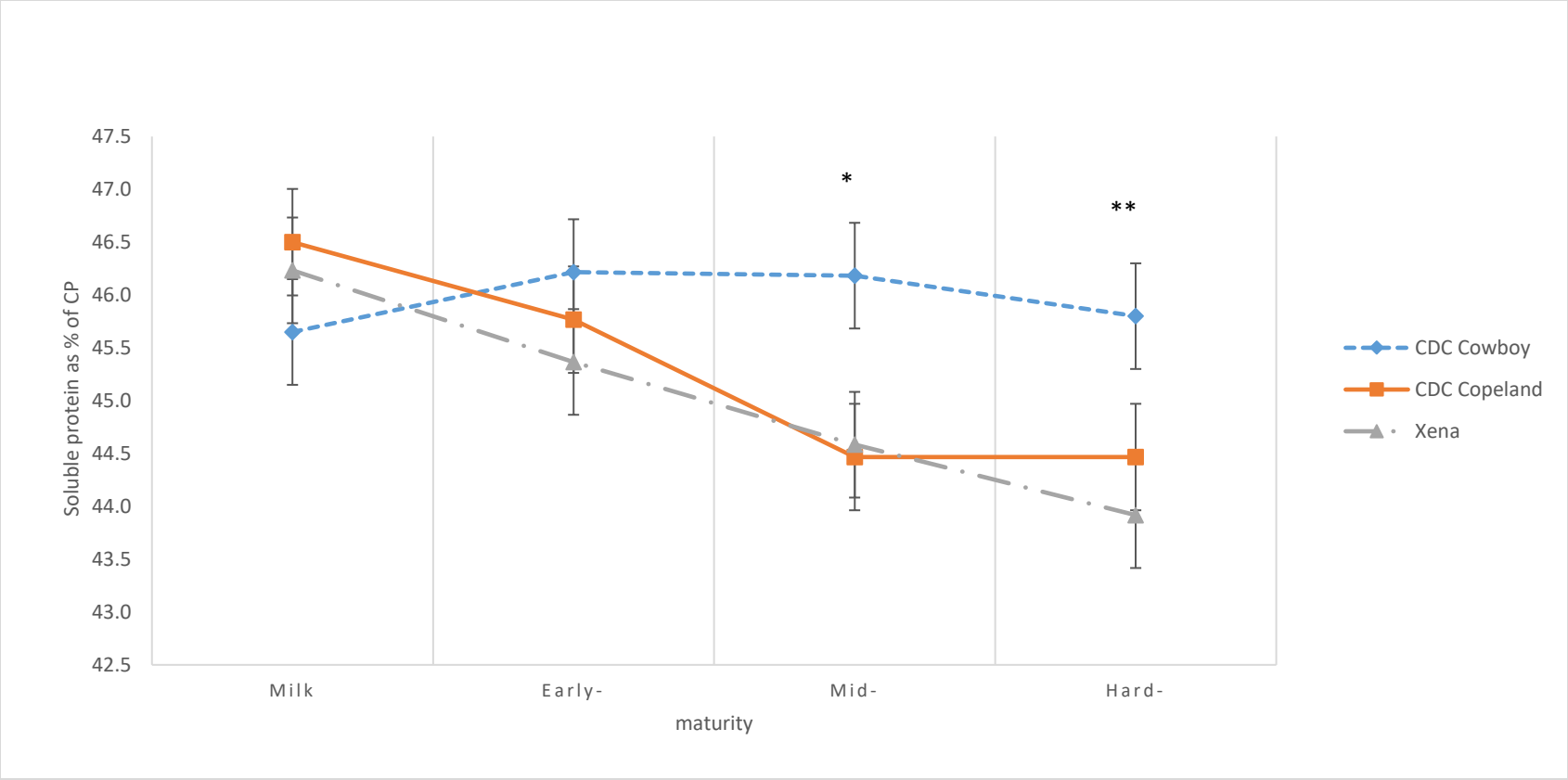

Figure 6. 1. Effect of barley variety and stage of maturity at harvest on soluble protein as a percent of crude protein.

* indicates CDC Cowboy greater than CDC Copeland and Xena ($P < 0.01$) at mid-dough stage.

** indicates CDC Cowboy greater than Xena and CDC Copeland intermediate ($P < 0.01$) at hard-dough stage.

interaction with CDC Cowboy having similar SP across all stages of plant maturity while CDC Copeland and Xena exhibited a decrease with advancing maturity (Figure 6.1). At mid-dough, CDC Cowboy had greater ($P < 0.01$) SP relative to CDC Copeland and Xena while at hard-dough, CDC Cowboy had greater SP content relative to Xena with CDC Copeland intermediate. The SP fraction of crude protein is soluble in the rumen (Licitra et al. 1996; Hedqvist and Udén 2006) which consists of both non-protein nitrogen and some true protein. Barley green feed at the milk stage contains higher SP content relative to the hard-dough stage. Soluble protein is rapidly degraded by ruminal microbes and is used for bacterial protein synthesis. The greater SP content of CDC Cowboy green feed indicates that when harvested at the recommended mid-dough stage of maturity, this variety provides greater SP for ruminal bacterial crude protein synthesis than either CDC Copeland or Xena.

The acid (ADICP) and neutral detergent insoluble crude protein (NDICP) content (% DM basis) were greater ($P < 0.01$) for CDC Cowboy relative to CDC Copeland and Xena. Nair et al. (2016a) reported a numerically greater ADICP and NDICP content in CDC Cowboy silage as compared to the other two varieties when all were harvested at mid-dough. Greater ADICP and NDICP of CDC Cowboy is likely due to the greater ADF and NDF content of this variety relative to Xena (Table 6.4). Acid detergent insoluble crude protein (ADICP) includes the fraction of protein that is associated with ADF residue. While forages naturally contain some ADICP, it generally represents heat damaged protein and protein associated with lignin (Licitra et a. 1996). The ADICP fraction, particularly in heat damaged forages is considered unavailable to ruminal microbes and is not digested by the proteolytic enzymes in the small intestine (Goering et al. 1972). Similar to ADICP, NDICP represents the CP associated with the cell wall (NDF). The NDICP represents the B3 fraction of protein in the CNCPS feed evaluation system

which is slowly degraded in the rumen. Depending on the nature of the feed and ruminal passage rate, a considerable fraction of NDICP can be made available for absorption in the small intestine.

Crude protein, SP and NDICP content decreased while ADICP increased ($P < 0.01$) with advancing barley maturity (Table 6.3). As ADICP includes protein associated with lignin and since lignin as a percent of NDF increases as plant matures, ADICP is expected to also increase with advancing maturity. A decrease in NDICP in the present study is interesting as it has been reported that mature forages contain a considerable amount of NDICP (Hassanat et al. 2006; Yari et al. 2014; Hakl et al. 2015). These authors reported that the NDICP of whole crop pearl millet, lucerne and alfalfa forages respectively, increased with advancing maturity. The decrease in NDICP of barley varieties with advancing maturity in our study is likely due to a decrease in the protein fraction associated with hemicellulose. Even though we did not report hemicellulose, when calculated as the difference between NDF and ADF, hemicellulose content decreased with advancing maturity (data not shown). The decline in CP content of whole crop barley forage with advancing maturity is consistent with Wallsten et al. (2009) who reported a decrease in CP with advancing maturity of barley green feed from early-milk (11.5%) to early-dough (9.8%) stage (% DM basis). This decrease is likely due to the concurrent increase ($P < 0.01$) in starch content (Table 6.4) that occurs as the plant matures.

CDC Cowboy had a higher ADF and NDF content ($P < 0.01$) across all stages of maturity relative to Xena with CDC Copeland intermediate (Table 6.4). A higher ADF (33.0%) and NDF (52.6%) content (% DM basis) for CDC Cowboy green feed was also reported by Gill et al. (2013) relative to other barley varieties evaluated. In a companion study at Lethbridge,

Table 6. 4. Effect of variety and stage of maturity at harvest on carbohydrate and energy fractions of common barley varieties grown for silage

	Variety			Stage of maturity at harvest					*P* value		
	CDC Cowboy	CDC Copeland	Xena	Milk	Early-dough	Mid-dough	Hard-dough	SEM	V	M	V × M
Item (% DM basis unless otherwise stated)											
ADF	31.1a	28.9b	27.5c	34.0a	29.0b	27.4c	26.2d	1.60	< 0.01	< 0.01	0.16
NDF	54.2a	53.1a	49.4b	60.6a	51.5b	48.3c	48.5c	2.33	< 0.01	< 0.01	0.97
Lignin	4.13a	3.91b	3.70c	4.26a	3.95b	3.77c	3.68c	0.172	< 0.01	< 0.01	0.40
Lignin, % of NDF	8.57	8.49	8.41	7.94b	8.63a	8.64a	8.75a	0.096	0.10	< 0.01	0.55
NFC[a]	32.2c	34.6b	36.4a	25.6d	34.9c	37.4b	39.6a	1.33	< 0.01	< 0.01	0.67
NSC[b]	25.6c	28.7b	30.9a	17.4d	28.8c	32.1b	35.2a	1.32	< 0.01	< 0.01	0.25
Sugars	5.90	5.28	5.72	7.08	5.92	5.16	4.37	0.421	< 0.01	< 0.01	< 0.01
Starch	19.7	23.4	25.1	10.3	22.9	26.9	30.8	0.93	< 0.01	< 0.01	< 0.01
Starch, % of NFC	59.2	64.8	67.0	39.8	65.3	71.9	77.7	0.96	< 0.01	< 0.01	< 0.01
TDN[c]	62.7b	64.8a	65.4a	61.0c	64.5b	65.5a	66.2a	1.02	< 0.01	< 0.01	0.64

Note: ADF, acid detergent fiber; NDF, neutral detergent fiber; NFC, nonfiber carbohydrate; NSC, nonstructural carbohydrate; ESC, ethanol soluble carbohydrate; TDN, total digestible nutrient. V, variety of barley; M, maturity at harvest; V × M, interaction between variety and maturity. Means without a common lower cased letter differ ($P < 0.05$)

[a]NFC calculated as NFC, % = 100 - (CP % + Fat % + Ash % + NDF % + NDFICP %)

[b]NSC calculated as NSC, % = sugars % + starch %

[c]TDN calculated as per Weiss summative equation (Weiss 1998)

Alberta, Preston et al. (2016a) reported similar ADF and NDF (% DM basis) for CDC Cowboy (26.5% ADF, 50.2% NDF) and CDC Copeland silages (27.1% ADF, 51.6% NDF) while these parameters were lower (25.2% ADF, 49.1% NDF) in Xena silage. The ADF and NDF content decreased ($P < 0.01$) as maturity at harvest advanced from milk to hard-dough stage. Nadeau (2009) reported 13 and 14% decrease respectively for NDF and ADF as maturity at harvest of whole-crop barley advanced from early-milk to early-dough. Similarly, Rosser et al. (2013) reported a linear ($P < 0.01$) decrease in NDF content for CDC Cowboy green feed with advancing maturity. The lower proportion of ADF and NDF with advancing plant maturity is likely due to a dilution effect as a result of deposition of starch in the kernel as the plant matures (Collar and Aksland 2001).

Lignin (% DM basis) was greater ($P < 0.01$) for CDC Cowboy relative to Xena with CDC Copeland intermediate (Table 6.4). Moreover, lignin concentration (% DM basis) decreased with advancing plant maturity. Khorasani et al. (1997) reported a quadratic effect for lignin content with advancing barley maturity. These authors reported that the lignin content of whole crop barley increased up to 2 weeks after the boot stage and decreased thereafter until harvest at mid-dough. Lignin content expressed as % NDF averaged 8.5 ± 0.42 (Mean ± SD) across varieties and increased ($P < 0.01$) with advancing plant maturity. This increase in lignin content would have a negative impact on forage fiber digestibility. Collar and Aksland (2001) reported that greater lignification with advancing maturity of small grain cereals reduces the digestible NDF content and energy value of forage, as lignin is not digestible and its presence reduces the digestibility of other cell wall constituents like cellulose and hemicellulose.

Xena had higher NFC and NSC concentrations ($P < 0.01$) relative to CDC Cowboy with CDC Copeland intermediate. Greater NFC and NSC content in Xena is likely a reflection of this

variety's higher starch content (Table 6.4) relative to the other varieties, as the NFC fraction consists of starch, simple sugars and soluble fiber (Ondarza 2000). Non-structural carbohydrates (NSC) include starches and sugars. Moreover, both NFC and NSC content increased ($P < 0.01$) with advancing plant maturity reflecting the increase in starch content as the plant matures. Both NFC and NSC are digested faster than most of the cell wall fractions (Ondarza 2000) and hence represent a readily available source of energy for ruminal microbes. Furthermore, a higher NFC increases the rate of fermentation during ensiling (Woolford 1984) and upon consumption it could also improve the efficiency of ruminal microbial protein synthesis (Downing and Gamroth 2007). Sugar content was greater ($P < 0.01$) for CDC Cowboy and Xena relative to CDC Copeland and decreased with advancing barley maturity. The sugar content as measured by NIR represents primarily mono- and disaccharides and is often equated with ethanol soluble carbohydrate content. These sugars are an important component of the water soluble carbohydrate content of plant tissues. The decrease in their content with advancing maturity likely reflects polymerization of sugars to form starches as the kernel develops and indicates a potential negative effect on ensiling (Nadeau 2007).

There was a significant V × M interaction ($P < 0.01$) for starch content (Figure 6.2). At the milk stage, CDC Cowboy (9.4%) and CDC Copeland (9.3%) had lower ($P = 0.02$) starch content (% DM basis) than Xena (12.3%). At early- and mid-dough, CDC Cowboy had a lower, while Xena had a higher ($P < 0.01$) starch content than CDC Copeland. At hard-dough, both Xena (32.9%) and CDC Copeland (32.8%) had a higher ($P < 0.01$) starch content (% DM basis) than CDC Cowboy (26.8%). Lower starch content (% DM basis) for silage samples of CDC Cowboy (14.7%) relative to CDC Copeland (21.0%) and Xena (20.0%) harvested at mid-dough was also reported by Nair et al. (2016). Similarly, Preston et al. (2016) reported lower ($P = 0.02$)

starch content (% DM basis) for CDC Cowboy (18.6%) green feed relative to Xena (23.0%) with CDC Copeland intermediate (19.0%). Moreover, Gill et al. (2013) reported that CDC Cowboy cut as green feed at mid-dough had a lower TDN content (63.2%) relative to other two or six row barley varieties (64.8% across varieties), likely due to a lower starch content.

CDC Copeland (64.8%) and Xena (65.4%) had greater ($P < 0.01$) TDN content relative to CDC Cowboy (62.7%), an observation similar to that of Gill et al. (2013). As TDN content of feed is calculated by a summative approach (Weiss 1998; NRC 2001) and is based on its nutrient composition and digestibility, the lower starch and higher ADF and NDF content of CDC Cowboy accounts for its lower TDN content. Moreover, across varieties, the TDN concentration of barley forage increased ($P < 0.01$) from milk to the hard-dough stage of maturity as a result of the greater accumulation of starch.

The effect of barley variety and stage of maturity at harvest on NDF digestibility characteristics are presented in Table 6.5 and Figures 6.3 to 6.5. There were ($P < 0.01$) V × M interactions for both the 6 ($NDFD_{6h}$) and 30 h ($NDFD_{30h}$) NDFD (Figures 6.3 to 6.5). Expressed as a % NDF, CDC Cowboy had lower ($P = 0.03$) $NDFD_{6h}$ relative to CDC Copeland and Xena at the milk stage (Figure 6.3). Varieties did not vary in $NDFD_{6h}$ at early-dough and averaged 10.6 ± 3.56 % (Mean ± SD). At mid-dough, Xena had greater ($P < 0.01$) $NDFD_{6h}$ relative to CDC Cowboy with CDC Copeland intermediate. However, at hard-dough, $NDFD_{6h}$ of CDC Copeland decreased and was similar to that of CDC Cowboy and was lower ($P < 0.01$) than Xena. When expressed as a % of digestible NDF (Figure 6.4), $NDFD_{6h}$ tended to increase with stage of maturity with no differences between varieties ($P = 0.12$) at the milk stage. However, at early-

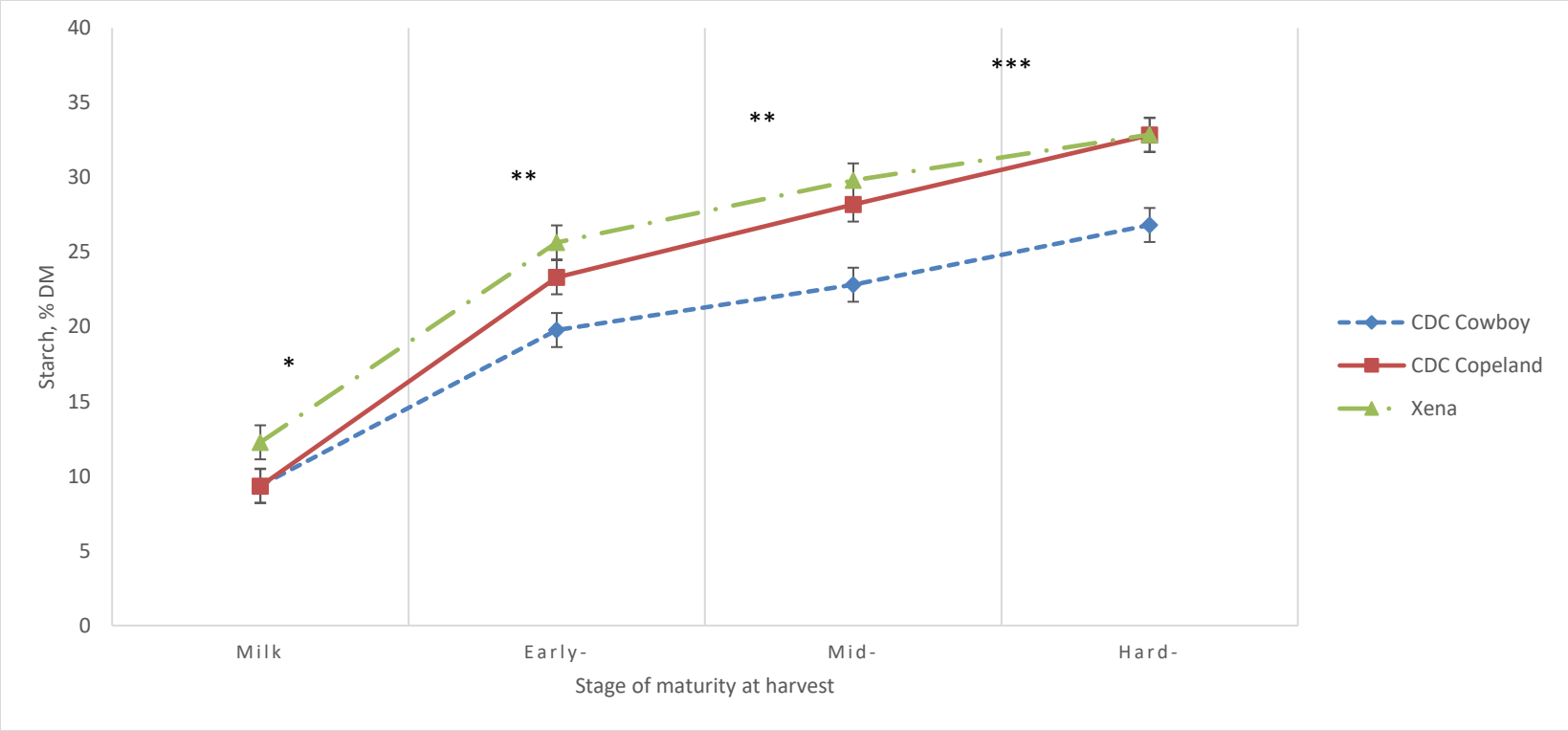

Figure 6. 2. Effect of barley variety and stage of maturity at harvest on starch content.

* indicates Xena greater than CDC Cowboy = CDC Copeland ($P < 0.05$) at milk stage.

** indicates Xena greater than CDC Cowboy and CDC Copeland intermediate ($P < 0.05$) at early- and mid-dough stage.

*** indicates Xena and CDC Copeland greater than CDC Cowboy ($P < 0.05$) at hard-dough stage.

Table 6. 5. Effect of barley variety and stage of maturity at harvest on NDF content and 30 h *in vitro* digestibility of DM and NDF

	Variety			Stage of maturity					*P* value		
Item (% NDF basis unless otherwise stated)	CDC Cowboy	CDC Copeland	Xena	Milk	Early-dough	Mid-dough	Hard-dough	SEM	V	M	V × M
$NDFD6_h$	10.8	12.2	13.2	10.6	10.5	13.0	14.1	1.18	< 0.01	< 0.01	< 0.01
$NDFD6_h$; % DNDF	19.9	23.0	22.8	16.9	18.7	25.1	27.0	1.96	< 0.01	< 0.01	< 0.01
$NDFD_{30h}$	39.9	38.3	38.7	45.1	40.1	36.9	33.7	1.70	< 0.01	< 0.01	< 0.01
$NDFD_{30h}$; % DNDF	72.2a	71.4a	67.1b	72.4a	71.4a	71.7a	65.4b	2.88	< 0.01	< 0.01	0.06
$INDF_{288h}$ (% DM)	24.6a	24.7a	21.0b	22.5	22.6	24.9	23.8	1.03	< 0.01	0.07	0.25
$INDF_{288h}$	45.0ab	46.1a	42.4b	37.6c	43.8b	48.2a	48.5a	1.61	0.03	< 0.01	0.72
DNDF	55.0ab	53.9b	57.6a	62.4a	56.2b	51.8c	51.5c	1.61	0.03	< 0.01	0.72

Note: $NDFD_{6h}$ and $NDFD_{30h}$, neutral detergent fiber digestibility as measured after 6- and 30-h *in vitro* incubation (Daisy^{II} system) respectively; $INDF_{288h,}$ indigestible NDF measured based on 288-h *in situ* incubation; DNDF, potentially digestible NDF; SEM, pooled standard error of mean. V, variety; M, maturity; V × M, interaction between variety and maturity. Means without a common lower cased letter differ (P < 0.05)

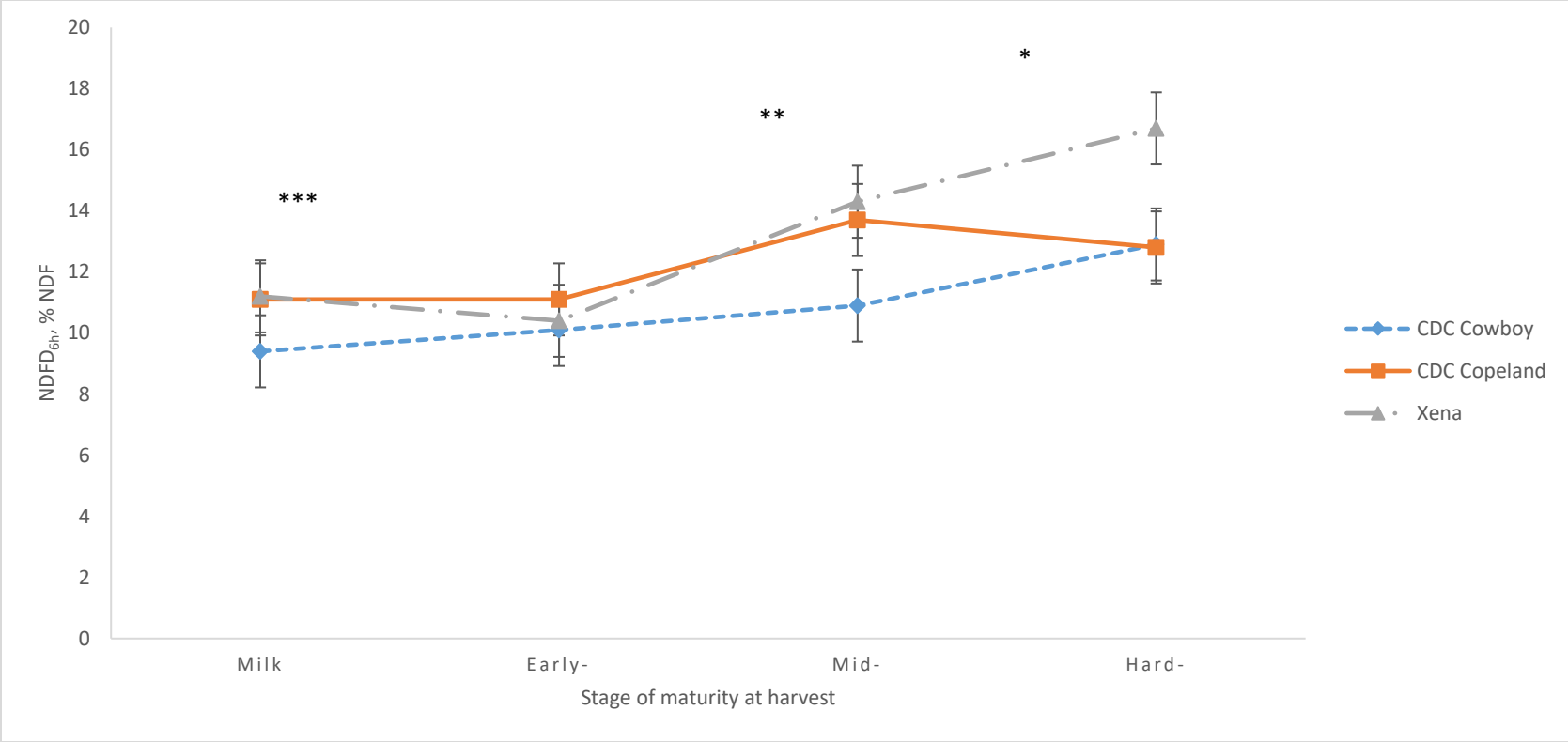

Figure 6. 3. Effect of barley variety and stage of maturity at harvest on $NDFD_{6h}$ (% of NDF basis).

*** indicates Xena and CDC Copeland greater than CDC Cowboy ($P < 0.05$) at early-dough stage.

** indicates Xena greater than CDC Cowboy and CDC Copeland intermediate ($P < 0.05$) at mid-dough stage.

* indicates Xena greater than CDC Cowboy = CDC Copeland ($P < 0.05$) at hard-dough stage

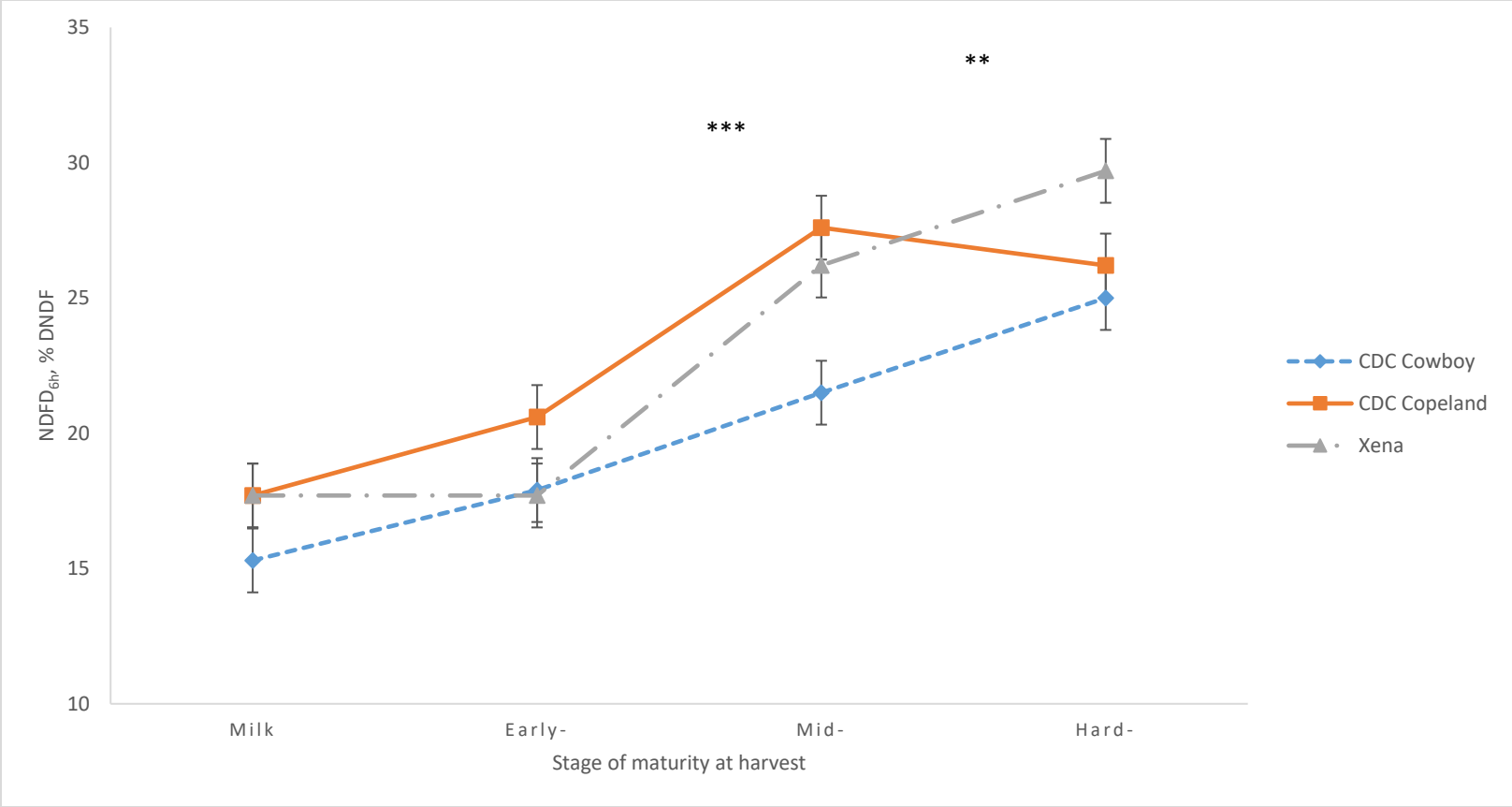

Figure 6. 4. Effect of barley variety and stage of maturity at harvest on $NDFD_{6h}$ (% of DNDF basis).

*** indicates Xena and CDC Copeland greater than CDC Cowboy ($P < 0.05$) at mid-dough stage.

** indicates Xena greater than CDC Cowboy and CDC Copeland intermediate ($P < 0.05$) at hard-dough stage.

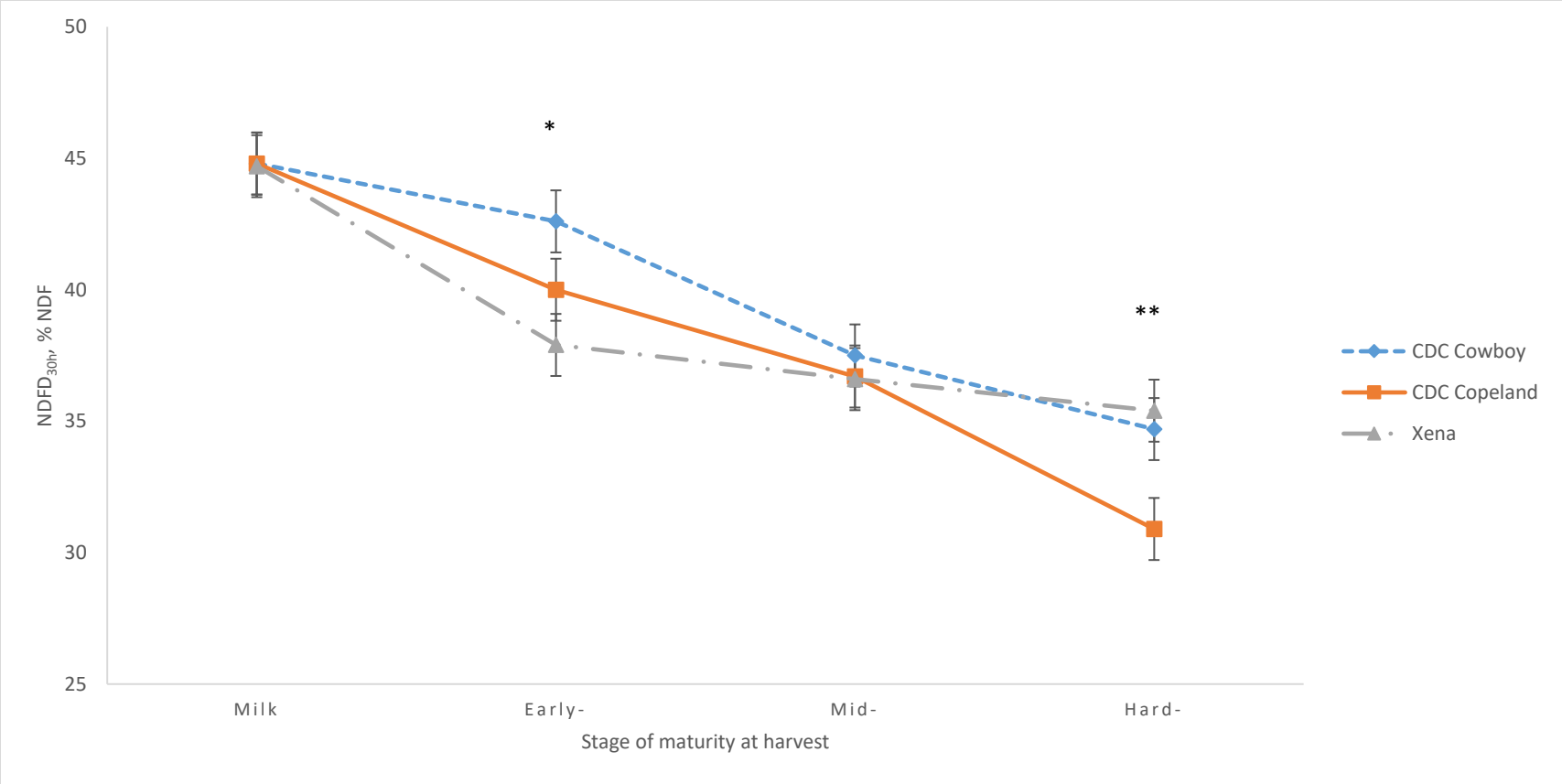

Figure 6. 5. Effect of barley variety and stage of maturity at harvest on $NDFD_{30h}$ (% of NDF basis).

* indicates CDC cowboy greater than Xena and CDC Copeland intermediate ($P < 0.01$) at early-dough stage.

** indicates CDC Cowboy and Xena greater than CDC Copeland ($P < 0.01$) at hard-dough stage.

and mid-dough, CDC Copeland had greater ($P \leq 0.05$) $NDFD_{6h}$ relative to CDC Cowboy with Xena intermediate. At hard-dough, Xena had greater ($P < 0.01$) $NDFD_{6h}$ relative to CDC Cowboy with CDC Copeland intermediate. All three barley varieties showed an increase ($P < 0.01$) in $NDFD_{6h}$ (% NDF and DNDF) with advancing maturity.

Ruminal fiber digestion begins with the attachment and colonization of ruminal microbes to forage particles (McAllister et al. 1994; Vagra and Kolver 1997). The time for this attachment to occur is often referred to as the lag time, a period that Van Soest et al. (2005) proposed aligns with 6 h *in vitro* NDFD. The V × M interaction for $NDFD_{6h}$ in the present study indicates that there is variability between varieties in terms of lag time. Thus, variety specific digestibility parameters will provide more accurate estimates of DMI, milk production and performance in modern feed evaluation systems.

Similar to $NDFD_{6h}$, there was also a ($P < 0.01$) V × M interaction for $NDFD_{30h}$ (Figure 6.5). Expressed as a % of NDF, the barley varieties did not vary ($P > 0.05$) in $NDFD_{30h}$ at milk and mid-dough and averaged 45.3 ± 3.88 % and 36.4 ± 6.78 % (Mean ± SD), respectively. Varieties however varied in $NDFD_{30h}$ at early- and hard-dough. These results indicate that barley varieties grown for silage in western Canada indeed differ in terms of $NDFD_{30h}$, with the magnitude and their ranking depending on stage of maturity. CDC Cowboy at the early-dough stage had greater ($P < 0.01$) $NDFD_{30h}$ (42.6%; % NDF basis) relative to Xena (37.9%) with CDC Copeland intermediate (40.0%). It is logical to assume that harvesting CDC Cowboy for forage at early-dough, rather than at the more conventional mid-dough stage will result in improved ruminal and total tract digestibility and likely production in ruminants fed high silage diets. Such a strategy would be particularly important for dairy producers. Greater NDFD of forages have

been reported to improve the DMI and milk yield in dairy cattle (Oba and Allen 1999) due to rapid

fermentation and ruminal disappearance of NDF. However, at hard-dough, $NDFD_{30h}$ was similar between CDC Cowboy and Xena and lowest ($P < 0.01$) for CDC Copeland. Rosser et al. (2013) reported greater yield of EDDM for CDC Cowboy for swath grazing as maturity at harvest advanced from the boot to the hard-dough stage. Based on the results of Rosser et al. (2013) and from that of the present study, it is likely that CDC Cowboy and Xena would yield greater EDDM relative to CDC Copeland at the hard-dough stage. Harvesting CDC Cowboy and Xena at this stage can be attractive to beef producers who place equal or greater emphasis on quantity versus quality of forage. A greater reduction in $NDFD_{30h}$ (36.7% to 30.9%) from mid-dough to hard-dough for CDC Copeland likely suggests that the ideal harvest stage for CDC Copeland for silage, green feed or for swath grazing is mid-dough.

CDC Cowboy had the greatest while Xena the lowest $NDFD_{30h}$ as a % of potentially digestible NDF (DNDF; Table 6.5). Moreover, $NDFD_{30h}$ (% DNDF basis) decreased ($P < 0.01$) with advancing maturity. Rosser et al. (2013) reported similar results in terms of *in situ* effective degradability of NDF (EDNDF) of barley green feed (cv. CDC Cowboy). These authors reported an EDNDF of 32.4% at the boot stage, 25.9% at late milk, 26.0% at hard-dough and 22.0% at full maturity. As described earlier, a decrease in NDFD with advancing maturity is closely related to greater lignification and crosslinking of the forage plant cell walls (Jung and Allen 1995). This cross linking physically prevents the ruminal microbes from attaching to and fermenting the cellulose and hemicellulose (Jung and Deetz 1993). An increase in lignin concentration (% NDF basis) with advancing maturity (Table 6.4) indicates a corresponding increase in indigestible NDF.

Nair et al. (2016a) reported $NDFD_{30h}$ (% NDF basis) of 37.0%, 31.1% and 28.8% for CDC Cowboy, CDC Copeland and Xena silages, respectively harvested for silage at mid-dough. These values are somewhat lower than those reported in the present study (Table 6.5). However, it should be noted that the $NDFD_{30h}$ values reported in the present study are the average of four stages of maturity ranging from milk to hard-dough. Moreover, the samples evaluated in the present study were green feed and did not go through the ensiling process as was the case in the study by Nair et al. (2016a). Indigestible NDF ($INDF_{288h}$) (% DM basis) of CDC Cowboy (24.6%) and CDC Copeland (24.7%) was greater than that of Xena (21.0%; Table 6.5). There was also a tendency ($P = 0.07$) for greater $INDF_{288h}$ with advancing barley maturity. Expressed as a % of NDF, $INDF_{288h}$ content of Xena (42.4%) was greater ($P = 0.03$) than that of CDC Copeland (46.1%) with CDC Cowboy intermediate (45.0%). Moreover, the $INDF_{288h}$ as a % of NDF increased ($P < 0.01$) with advancing barley maturity. These results reflect the greater NDF and lignin content for CDC Cowboy and CDC Copeland relative to Xena along with the increasing lignin content with advancing maturity (Table 6.4). Nair et al. (2016a) reported $INDF_{288h}$ values for the three varieties when ensiled to be similar in magnitude to that seen in the present study. However, in that study, CDC Cowboy had lower $INDF_{288h}$ values than CDC Copeland or Xena. The INDF denotes the un-digested fraction of the forage cell wall that provides no usable energy to the ruminant host (Traxler et al. 1998).

Potentially digestible NDF (DNDF) content (% NDF basis) of Xena (57.6%) was greater than that of CDC Copeland (53.9%) with CDC Cowboy intermediate (55.0%). Moreover, DNDF decreased with advancing maturity, reflecting the increase in $INDF_{288h}$. Greater DNDF content of Xena indicates that the contribution of NDF to digestible energy will be greater relative to that of CDC Copeland. As for $INDF_{288h}$, results of DNDF contrasts somewhat with that reported by Nair

et al. (2016a) who reported greater DNDF for CDC Cowboy (59.0%) as compared to CDC Copeland (47.2%) and Xena (48.8%). Differences in NDF content, type of sample (green feed vs silage) and environmental conditions including temperature and soil fertility during plant growth could potentially affect nutrient composition and subsequent digestibility.

The interaction between barley variety and stage of maturity in $NDFD_{30h}$ (% NDF basis) provides a potential opportunity for beef and dairy producers to manage their forage crop through selecting for varieties that exhibit improved fiber digestibility. Greater $NDFD_{30h}$ of barley varieties potentially allows for replacement of a portion of concentrate in diets without compromising production potential by the increased availability of dietary energy from the forage and potential for increased DMI. There are potential benefits of feeding greater forage concentrations in feedlot diets especially for finishing cattle. Higher levels of forage NDF increases the peNDF content of the diet and stimulates chewing and salivary buffering in the rumen. Improvements in ruminal pH of finishing steers fed higher forage levels reduces the incidence of ruminal acidosis, increases DMI with likely improvements in finishing performance. Further research is needed to evaluate the tradeoff between DM yield and forage quality when barley varieties are harvested at maturity other than the conventional mid-dough stage. Moreover, implications of the differences in $NDFD_{30h}$, NDF and starch content of barley varieties harvested at variety specific maturities has to be evaluated in terms of DMI and animal performance.

6.5 Conclusion

Barley varieties previously shown to vary in $NDFD_{30h}$ (% NDF basis) were evaluated for the effect of variety and stage of maturity at harvest on $NDFD_{30h}$. An observed V × M interaction indicated that $NDFD_{30h}$ (% NDF) varied with advancing maturity among the three barley varieties evaluated. Relatively greater $NDFD_{30h}$ (% NDF) for CDC Cowboy at early-dough versus the other two varieties indicates that there could be benefits to harvesting this variety before mid-dough. For producers who cut forage at the hard dough stage to balance both quantity and quality, the greater $NDFD_{30h}$ (% NDF) for CDC Cowboy and Xena at this stage indicates that the EDDM of these varieties is likely to be greater than that of CDC Copeland. A greater decline in $NDFD_{30h}$ for CDC Copeland at the hard dough stage indicates that this variety should be harvested no later than mid-dough. These results indicate that variety should be taken into consideration when deciding the stage of maturity at which to harvest barley forage. Greater lignification increases the $INDF_{288h}$ content (% NDF basis) with advancing maturity as indicated by a decrease in $NDFD_{30h}$ (% NDF basis) across all barley varieties. Further research is needed to evaluate the optimum stage of harvest for specific barley varieties whether harvested as green feed or silage on nutritive value and animal performance.

7.0 General Discussion

Detailed nutrient and digestibility characteristics of barley varieties grown for silage in western Canada have not been well characterized. As a result, producers are often faced with a lack of information on which variety to grow for silage particularly from a nutritional point of view. As such, producers tend to place more emphasis on agronomic than nutritional characteristics when making variety selections for silage. The objectives of the research were to i) evaluate the nutrient and $NDFD_{30h}$ of common barley varieties grown for silage in western Canada, ii) evaluate the effect of feeding barley varieties potentially varying in $NDFD_{30h}$ on feedlot performance, carcass characteristics, ruminal and total tract digestibility and ruminal particulate passage rate and iii) evaluate the effects of variety and stage of maturity at harvest on nutrient composition and $NDFD_{30h}$ of common forage barley varieties grown in western Canada. The hypothesis was that barley silage varieties with higher $NDFD_{30}$ will result in an increased ruminal degradation of forage cell wall components resulting in greater ruminal particulate passage rate, increased availability of dietary energy, higher DMI, increased ruminal pH and improved performance of backgrounding and finishing cattle relative to steers fed barley silage varieties with a lower $NDFD_{30}$.

In Chapter 3, silage samples were harvested at mid-dough and collected from commercial feedlot and dairy operations in south-central Saskatchewan and parts of Alberta and included both 2 and 6 row varieties, feed and malting types having either smooth or rough awns. This evaluation indicated that there is significant variability among barley varieties in terms of nutrient composition. For example, Baron et al. (2000) and Gill et al. (2013) reported that there is variability among barley varieties for forage quality. Baron et al. (2000) reported that semi-dwarf barley varieties (cv. Tukwa) have greater CP content and *in vitro* OM digestibility along with a

lower ADF and NDF content relative to standard barley varieties (cv. Virden) harvested at early-dough. Similarly, Gill et al. (2013) reported that 2 row barley varieties had greater DM yield and lower NDF content relative to 6 row varieties when harvested at mid-dough. The range in nutritional characteristics of barley silage collected clearly indicated that barley varieties vary in nutrient and digestibility characteristics even when harvested at the same maturity. Consequently, there is potential for plant breeders to select barley varieties for nutritional characteristics that could allow producers to grow barley silage with improved nutrient and digestibility parameters.

In chapter 3, the CP content ranged from 10.2 (Xena) to 12.5% (Falcon), NDF from 41.6% (Legacy) to 48.6% (CDC Cowboy) and starch from 14.7% (CDC Cowboy) to 24.7% (Legacy). Barley varieties with greater CP content like Falcon and AC Metcalfe are of value in feed formulations for high producing dairy cattle and rapidly growing beef cattle as they could lower supplemental protein costs. Interestingly, CDC Cowboy had the greatest NDF content and lowest starch content of the varieties examined. Moreover, CDC Cowboy had the greatest $NDFD_{30h}$ (37.0%) followed by CDC Copeland (31.1%), Falcon (31.6%), AC Metcalfe (30.8%), Xena (28.8%) and Legacy (27.6%).

Feeding trials using growing beef cattle (Chapter 4, 5) were conducted to examine to what extent the greater $NDFD_{30h}$ of CDC Cowboy could offset its c lower starch content. However, as opposed to what was expected based on the results of Chapter 3, these varieties did not vary in $NDFD_{30h}$ (% NDF basis) in either the feedlot or metabolism studies (Chapter 4 and 5). This may reflect the fact that the varieties were grown at the same location using similar agronomic practices. These results indicate the difficulties in choosing barley forage varieties based on a single chemical or nutritional parameter like $NDFD_{30h}$, as it may not be possible to

obtain consistent plant characteristics over multiple crop years. For example, Gill et al. (2013) reported a significant year effect on nutrient composition of barley varieties evaluated over multiple crop years. These authors reported a range of 8.2% to 11.8% for CP, 25.5% to 37.2% for ADF and 41.8% to 59.7% for NDF content for barley varieties evaluated over 3 crop years. Further research in terms of genetic selection is required for nutrient and $NDFD_{30h}$ characteristics before these nutritional parameters are used as selection criteria to select which variety to grow for silage.

It is important to note that barley varieties with similar NDF content had varying INDF content and $NDFD_{30h}$ when harvested at same stage (mid-dough) of maturity (Chapter 3). For example, CDC Cowboy and AC Metcalfe had similar NDF content (48.6 vs 47.3%) while CDC Cowboy had lower INDF (41.0 vs 58.0%) and greater $NDFD_{30h}$ (37.0 vs 30.8%) than AC Metcalfe when both were harvested at mid-dough. These results indicate that detailed nutrient analysis including $NDFD_{30h}$ and INDF will provide more accurate digestible energy predictions in mechanistic rumen models. As evidenced from the INDF content, CDC Cowboy has a greater potentially digestible NDF pool relative to AC Metcalfe despite both having a similar NDF content. It is logical to assume that potential contribution of NDF to digestible energy content is greater for CDC Cowboy relative to AC Metcalfe.

CDC Copeland had relatively lower NDF (44.3 vs 48.6%) and lignin (3.71 vs 4.40%) content than CDC Cowboy. However, $NDFD_{30h}$ of CDC Copeland was lower (31.1vs 37.0%) than that of CDC Cowboy. Greater lignification has consistently been reported to be associated with lower cell wall digestibility (Jung and Allen 1995). However, the results of the present study likely indicate that lignin cross linking rather than concentration has greater effect on cell wall digestibility. This observation corresponds to the greater decrease in $NDFD_{30h}$ for CDC

Copeland relative to CDC cowboy or Xena with advancing maturity from mid- to hard-dough. (Chapter 6). Accordingly, effectively degradable dry matter yield of CDC Copeland is likely lower than that of CDC Cowboy or Xena when harvested at hard-dough especially for feedlot operations who give equal or more emphasis on the quantity of silage yield as opposed to quality.

Greater $NDFD_{30h}$ of CDC Cowboy was expected to result in improved performance in feedlot steers. Moreover, substituting CDC Cowboy for barley grain in backgrounding and finishing diets was hypothesized to result in similar or improved feedlot performance of steers due to its expected higher $NDFD_{30h}$. However, the backgrounding and finishing feedlot study (Chapter 4) showed that steers fed CDC Cowboy resulted in poorer performance during backgrounding relative to steers fed CDC Copeland or Xena, with no effect of variety on finishing performance. As indicated earlier, the barley varieties used for the feedlot and metabolism studies did not vary in $NDFD_{30h}$. The lack of a difference in $NDFD_{30h}$ among barley silage varieties could potentially be the reason for the absence of the variety × inclusion level interaction during backgrounding or finishing. Poorer performance of steers fed CDC Cowboy during backgrounding was attributed to its greater NDF content of relative to the other varieties. As the backgrounding diets varied in terms of ADF, NDF and starch content and not in $NDFD_{30h}$, it is logical to assume that factors like NDF and starch content cam also influence DMI and the growth performance of backgrounding steers.

According to Mertens (1996, 2010) and Allen (2000), dietary NDF regulates DMI in cattle fed high forage diets through gut fill. Forage NDF is less dense, digested slowly and retained in the rumen longer than other dietary components (Allen and Bradford 2009). A review of the literature indicates significant negative correlation between NDF content of the diet and

DMI in beef (Reid et al. 1988) and dairy cattle (Dado and Allen 1996; Oba and Allen 1999; Arelovich et al. 2008). It is likely that the lower DMI and poorer performance of steers fed CDC Cowboy during backgrounding is in part a result of greater NDF content of the diets containing this variety (41.8 vs. 36.6%). Lower DMI results in lower dietary energy intake and poorer performance. Steers fed CDC Cowboy had 0.50 Mcal lower (8.55 vs 9.05 Mcal d^{-1}) NEg intake relative to steers fed CDC Copeland and 0.69 Mcal lower NEg intake (8.55 vs 9.24 Mcal d^{-1}; $P < 0.01$) than those fed Xena during backgrounding (Study 4). Similarly, HIGH relative to LOW silage diets during backgrounding had greater NDF content (40.1 vs 36.5%). Moreover, steers fed HIGH relative to LOW silage diets during backgrounding had lower NEg intake (8.54 vs 9.36 Mcal d^{-1}; $P < 0.01$). As NE_g is defined as the energy content of deposited tissue and is a function of the proportion of fat and protein in empty body tissue gain, a lower NEg intake corresponds to poorer backgrounding performance.

As indicated earlier, there was no effect of variety of barley on any of the measured finishing performance parameters. However, steers fed HIGH silage diets during backgrounding compensated for the poorer backgrounding performance by compensatory gain during finishing as indicated by the greater ($P < 0.01$) ADG (1.65 vs. 1.54 kg), DMI (10.5 vs. 9.9 kg d^{-1}) and DMI as a % of BW (2.06 vs. 1.94%) relative to steers fed LOW silage diets. This observation is interesting as finishing steers fed HIGH silage diets had 10% less barley grain (77.0 vs. 87.0%, % DM basis) in the diet relative to those fed the LOW silage diets. Greater barley silage levels during finishing will have positive effects on gut health and ruminal pH as high grain diets are often associated with ruminal acidosis. This is evidenced from the fact that heifers fed HIGH silage finishing diets (Study 5) had greater ($P < 0.01$) ruminal pH (6.25 vs 6.04) relative to those fed LOW silage diets. Moreover, heifers fed HIGH silage diets had relatively lower duration

under pH 5.8 (288.0 vs 593.5 min d^{-1}; $P = 0.05$) and 5.5 (123.5 vs 298.5 min d^{-1}; $P = 0.08$) relative to those fed LOW silage diets. Greater ($P < 0.01$) NDF (23.1 vs 19.5%) and lower starch (49.6 vs 54.5%) content (% DM basis) improves the ruminal pH of heifers fed HIGH relative to LOW silage diets by increasing rumination and salivation during finishing. Improved performance of steers fed relatively lower levels of barley grain in the diet during finishing following a period of energy restriction during backgrounding provides an opportunity for producers to include greater forage levels in backgrounding and finishing diets thereby reducing feeding costs and improving ruminal health.

Apparent total tract digestibility did not vary ($P > 0.05$) among beef heifers fed HIGH or LOW silage finishing diets for any of the measured nutrient parameters (Study 5). However, there was a numerical increase (52.9 vs 48.6%) in NDF digestibility and a trend ($P = 0.06$) for increase (44.9 vs 38.1%) in ADF digestibility for heifers fed HIGH relative to LOW silage finishing diets. These improvements in fiber digestibility correlate to the improved mean ruminal pH and relatively shorted duration under pH 5.8 and 5.5 for heifers fed HIGH relative to LOW silage finishing diets. Relatively greater mean ruminal pH (6.13 vs 5.89; $P = 0.06$) for heifers fed HIGH relative to LOW silage diets indicate that the ruminal environment was more favorable for cellulolytic bacteria to digest plant cell walls (Russell and Wilson 1996) in heifers fed HIGH relative to LOW silage diets.

In an evaluation of effect of barley variety and stage of maturity at harvest on nutrient and $NDFD_{30h}$ characteristics of common barley varieties in western Canada (Chapter 6), Nair et al. (2017, submitted) reported no variability in $NDFD_{30h}$ between varieties when harvested at either milk or mid-dough. However, there was a V × M interaction where at early- and hard-dough variety specific harvest maturity targets would likely improve the nutritive value of silage

and could lead to specific maturity targets for different farm operations (i.e. beef vs. dairy) even within varieties. For example, CDC Cowboy at early-dough had greater ($P < 0.01$) $NDFD_{30h}$ (42.6%; % NDF basis) relative to Xena (37.9%) with CDC Copeland intermediate (40.0%). It is logical to assume that harvesting CDC Cowboy for forage at early-dough rather than the conventional mid-dough will result in improved ruminal and total tract digestibility and production performance in high producing animals. Such a strategy may prove attractive to dairy producers who are interested in optimizing forage quality. At hard-dough, CDC Cowboy and Xena had similar $NDFD_{30h}$ while CDC Copeland had the lowest ($P < 0.01$) value. A greater reduction in $NDFD_{30h}$ (36.7% to 30.9%) from mid-dough to hard-dough for CDC Copeland likely indicates that the ideal harvest maturity for silage or green feed for CDC Copeland is mid-dough as beyond this stage$NDFD_{30h}$ rapidly declines relative to CDC Cowboy or Xena. For beef producers who are interested in both forage quality and quantity, harvesting CDC Cowboy and Xena at hard-dough is likely a better option.

Studies with high NDFD forages (i.e. bmr corn) have previously been shown to improve the DMI and milk yield in dairy cattle (Oba and Allen 1999). These improvements in dairy cow performance were attributed to reduced ruminal fill, increased ruminal turnover of NDF and potential improvements in dietary energy status in cattle fed the high NDFD forage (Mertens 1987; Oba and Allen 1999b; Oba and Allen 2000). The bmr corn used in the study of Oba and Allen (1999) had relatively lower NDF (38.3 vs 40.1%), lignin (1.7 vs 2.5%) but similar starch (33.1 vs 33.3%) content and greater $NDFD_{30h}$ (49.1 vs 39.4%) relative to isogenic corn. In the present study, CDC Cowboy had greater ADF and NDF content and lower starch content relative to other varieties evaluated. Variability in nutrient composition among barley varieties potentially varying in $NDFD_{30h}$ likely confounds the effect of $NDFD_{30h}$ on performance of beef

and dairy cattle. As for corn, development of barley with lower NDF and lignin content and greater $NDFD_{30h}$ holds promise for improvements in beef cattle performance in western Canada. Stephens and Halpin (2008) reported that orange lemma mutant barley resembles bmr corn in that the lignin content is 10-15% lower for the mutant barley relative to isogenic barley. Moreover, Meyer et al. (2005) reported that orange lemma mutant barley has relatively lower lignin (4.0 vs 4.3%) and greater IVDMD (62.1 vs 58.7%) compared to isogenic barley. The bmr mutation in corn is associated with a lower grain yield and increased lodging (Cherney et al. 1991). Studies indicated that the DM yield of bmr corn is about 10% lower than the isogenic variety (Bernard 2010). However, Meyer et al. (2005) reported similar DM yield (9.3 vs 9.5 tons ha^{-1}) for orange lemma mutant vs isogenic barley. Further research on incorporation of the orange lemma mutation in barley varieties holds promise to reducing the lignin content and increase the $NDFD_{30h}$ of barley varieties.

In summary, barley varieties commonly grown for silage in western Canada vary in terms of starch, ADF and NDF content and $NDFD_{30h}$ when harvested at the conventional stage of mid-dough. Both variety of barley and level of inclusion in the diet affected performance of growing beef cattle with varieties like CDC Cowboy resulting in poorer backgrounding performance relative to varieties like CDC Copeland and Xena even though $NDFD_{30h}$ was similar across varieties. Moreover, HIGH relative to LOW silage diets resulted in poorer backgrounding performance. Greater NDF content of CDC cowboy and HIGH silage diets negatively affected DMI and backgrounding performance. However, ruminal pH parameters were improved by CDC Cowboy and HIGH silage diets for heifers fed backgrounding diets. Improved ruminal pH of heifers fed HIGH silage finishing diets tended to improve total tract ADF and NDF digestibility. Greater $NDFD_{30h}$ for CDC cowboy at early-dough and a decrease in $NDFD_{30h}$ for CDC

Copeland at hard-dough indicates that variety specific harvest maturity targets would likely improve the nutritive value of silage and could lead to specific maturity targets depending on targeted rumen function outcomes (i.e. beef vs. dairy). Moreover, there is potential for selection pressure by plant breeders for improved $NDFD_{30h}$ that allow producers to select barley varieties with enhanced nutritional and agronomic characteristics.

8.0 General Conclusion

Genetic selection for improved agronomic traits has resulted in variability among barley varieties for forage quality. However, producers are often faced with a lack of information on which variety to grow for silage particularly from a nutritional point of view. Variability in terms of ADF, NDF and starch content and $NDFD_{30h}$ for seven barley varieties harvested and ensiled at mid-dough indicated that variety has significance in terms of nutrient composition and digestibility of barley silage and thus is important when making a decision on the variety to grow for silage.

However, subsequent studies indicated that the barley varieties previously shown to vary in $NDFD_{30h}$ had similar NDF digestibility parameters when seeded, treated, harvested and ensiled similarly at mid-dough. Steers fed CDC Cowboy relative to those fed CDC Copeland or Xena during backgrounding had poorer performance due to greater NDF content of the variety which presumably limited DMI by gut fill. However, ruminal pH parameters were improved for heifers fed CDC cowboy and HIGH silage backgrounding diets and those fed HIGH silage finishing diets. Increase in ruminal pH parameters during finishing improved DMI and tended to improve total tract digestibility of ADF and NDF corresponding to greater DMI, ADG and G:F of steers fed HIGH silage diets during finishing.

The V × M interaction for starch and $NDFD_{30h}$ characteristics with advancing maturity of barley varieties indicated that variety of barley needs to be taken into account when making decisions on the stage of maturity at harvest that suits the type of farm operation. A greater $NDFD_{30h}$ at early-dough for CDC Cowboy relative to CDC Copeland or Xena indicates that harvesting this variety at earlier than the conventional mid-dough stage could result in improved

ruminal and total tract digestibility and likely production in high producing animals. Such a strategy would be particularly important for dairy producers. However, relatively greater $NDFD_{30h}$ for CDC Cowboy and Xena than CDC Copeland at hard-dough likely indicates that harvesting these varieties at a slightly later stage will yield greater degradable dry matter that benefits beef producers who place equal or greater emphasis on quantity versus quality of forage. A greater reduction in $NDFD_{30h}$ of CDC Copeland indicates that this variety needs to be harvested no later than at mid-dough.

Nutritional evaluation of seven common barley varieties grown for silage in western Canada indicates that there is potential for selection pressure by plant breeders for improved $NDFD_{30h}$ that allow producers to select barley varieties with enhanced nutritional and agronomic characteristics. However, further research is needed to use nutrient parameters like $NDFD_{30h}$ as a criterion for selecting an appropriate barley variety for forage production for beef and dairy producers in western Canada. Variety specific harvest maturity targets would likely improve the nutritive value of silage and could lead to specific maturity targets for different farm operations (i.e. beef vs. dairy). Further research is needed to evaluate the optimum stage of harvest for specific barley varieties whether harvested as green feed or silage on nutritive value and animal performance.

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10. Appendix

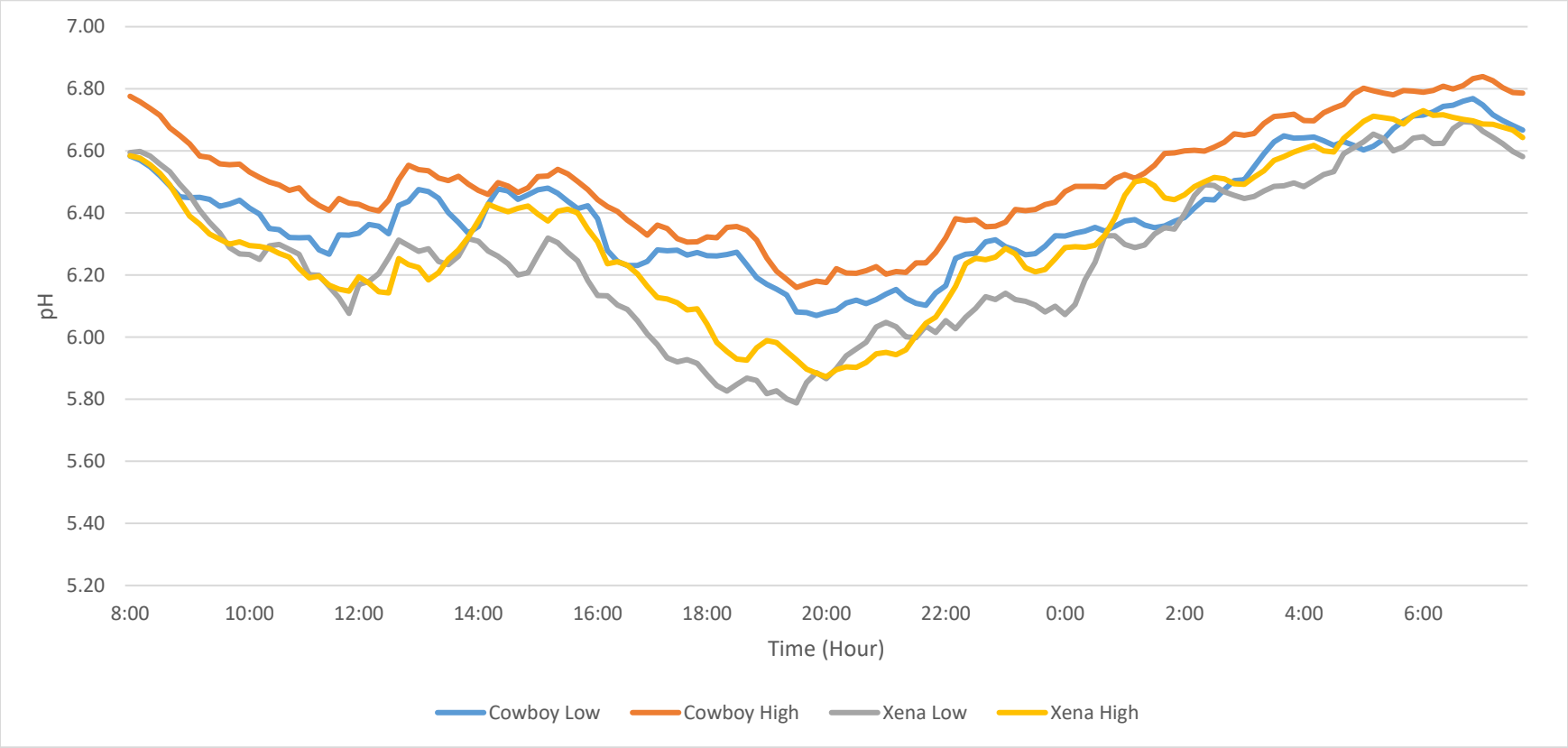

Figure 1. Effect of variety and level of inclusion of barley varieties in backgrounding diets of feedlot heifers on rumen pH using in-dwelling pH probes, averaged over a 24 h feeding period.

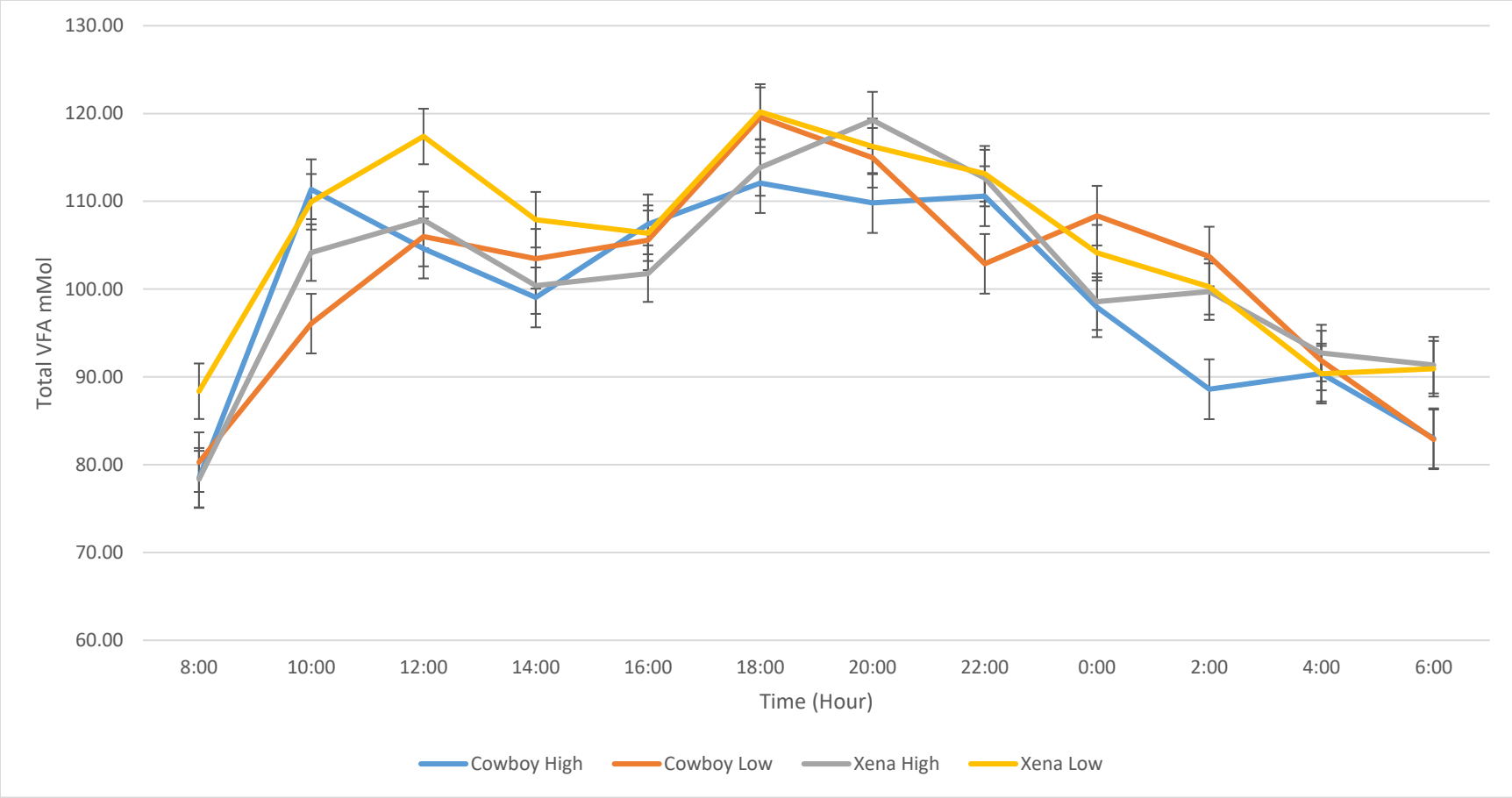

Figure 2. Effect of variety and level of inclusion of barley varieties in backgrounding diets of feedlot heifers on total volatile fatty acid concentration (mmol) averaged over a 24 h feeding period.

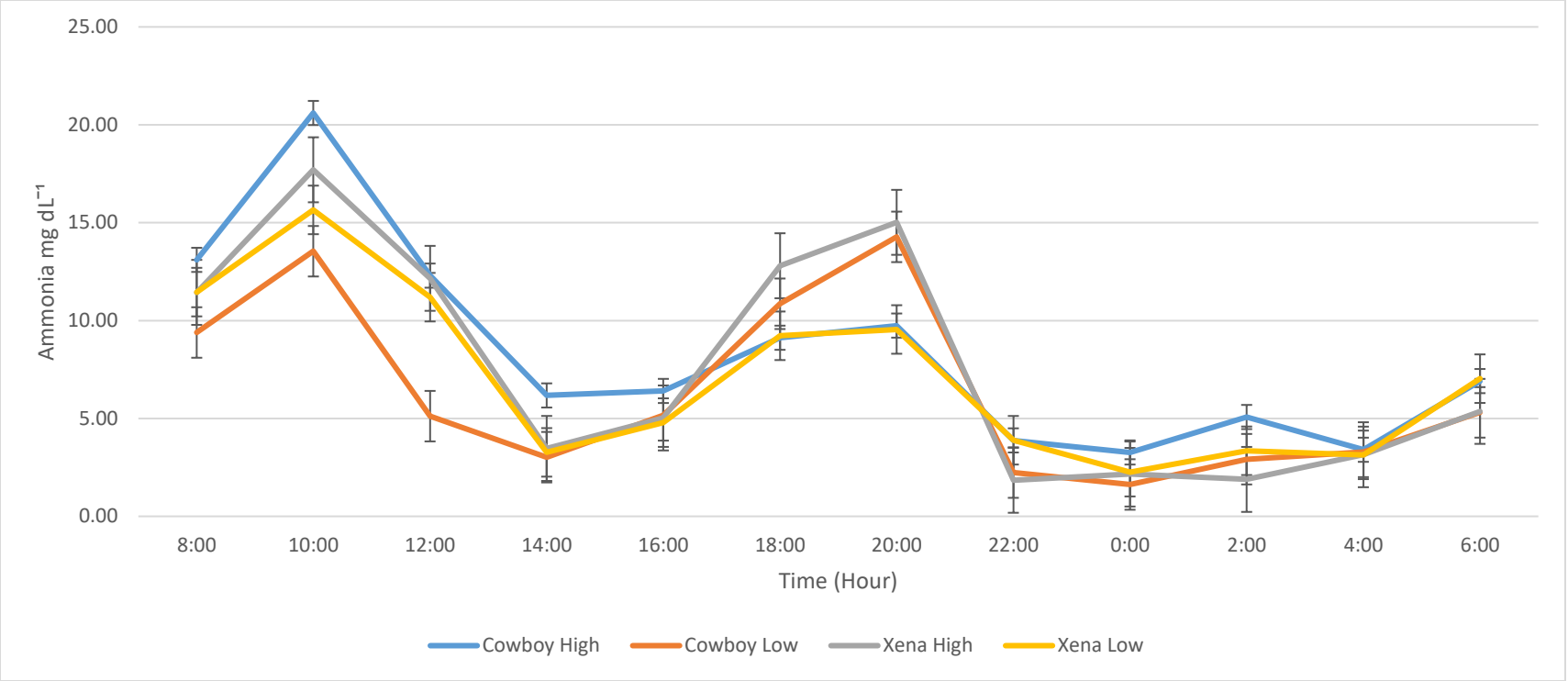

Figure 3. Effect of variety and level of inclusion of barley varieties in backgrounding diets of feedlot heifers on ruminal ammonia concentration (mg dL^{-1}) averaged over a 24 h feeding period.

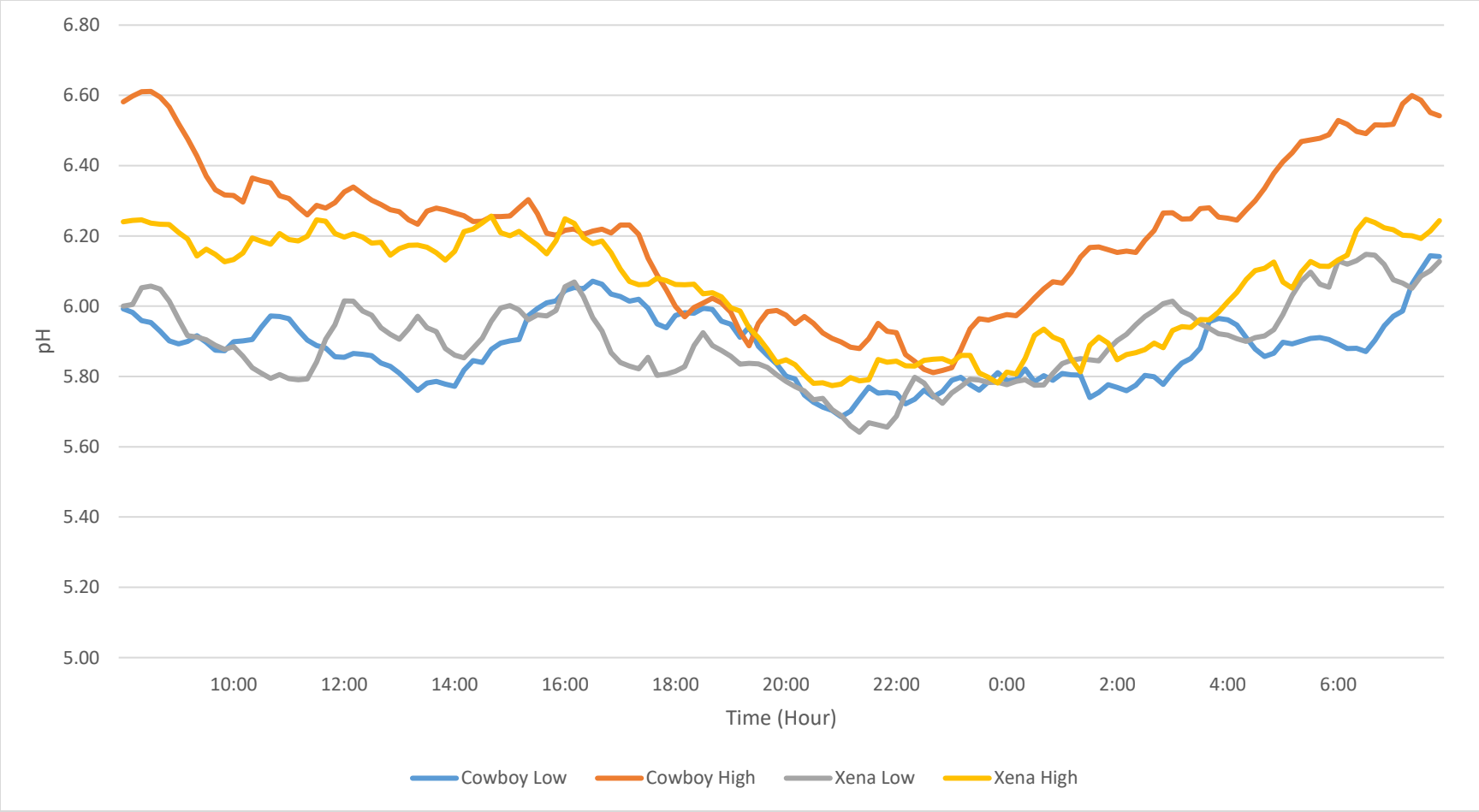

Figure 4. Effect of variety and level of inclusion of barley varieties in finishing diets of feedlot heifers on rumen pH using in-dwelling pH probes, averaged over a 24 h feeding period.

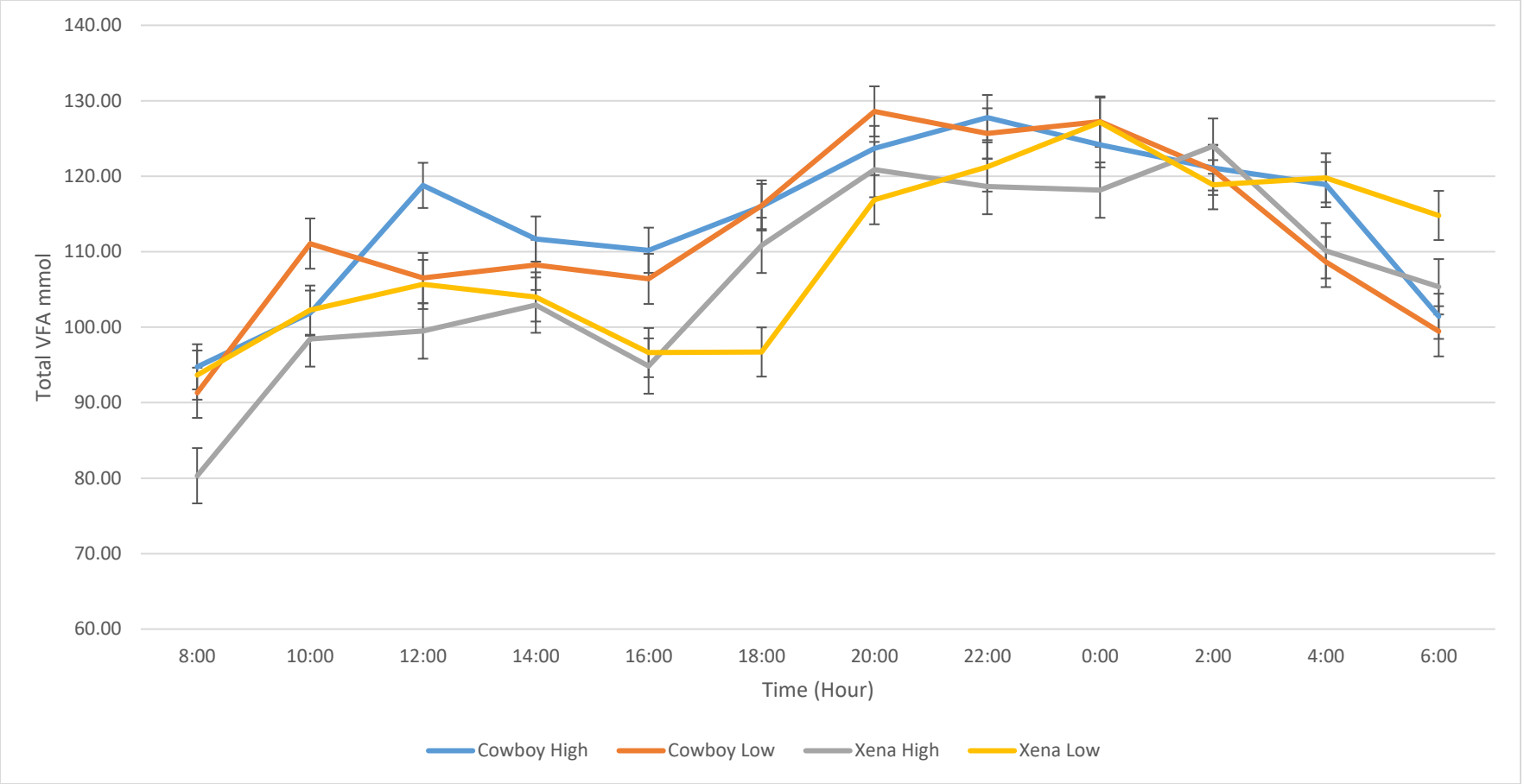

Figure 5. Effect of variety and level of inclusion of barley varieties in finishing diets of feedlot heifers on total volatile fatty acid concentration (mmol) averaged over a 24 h feeding period.

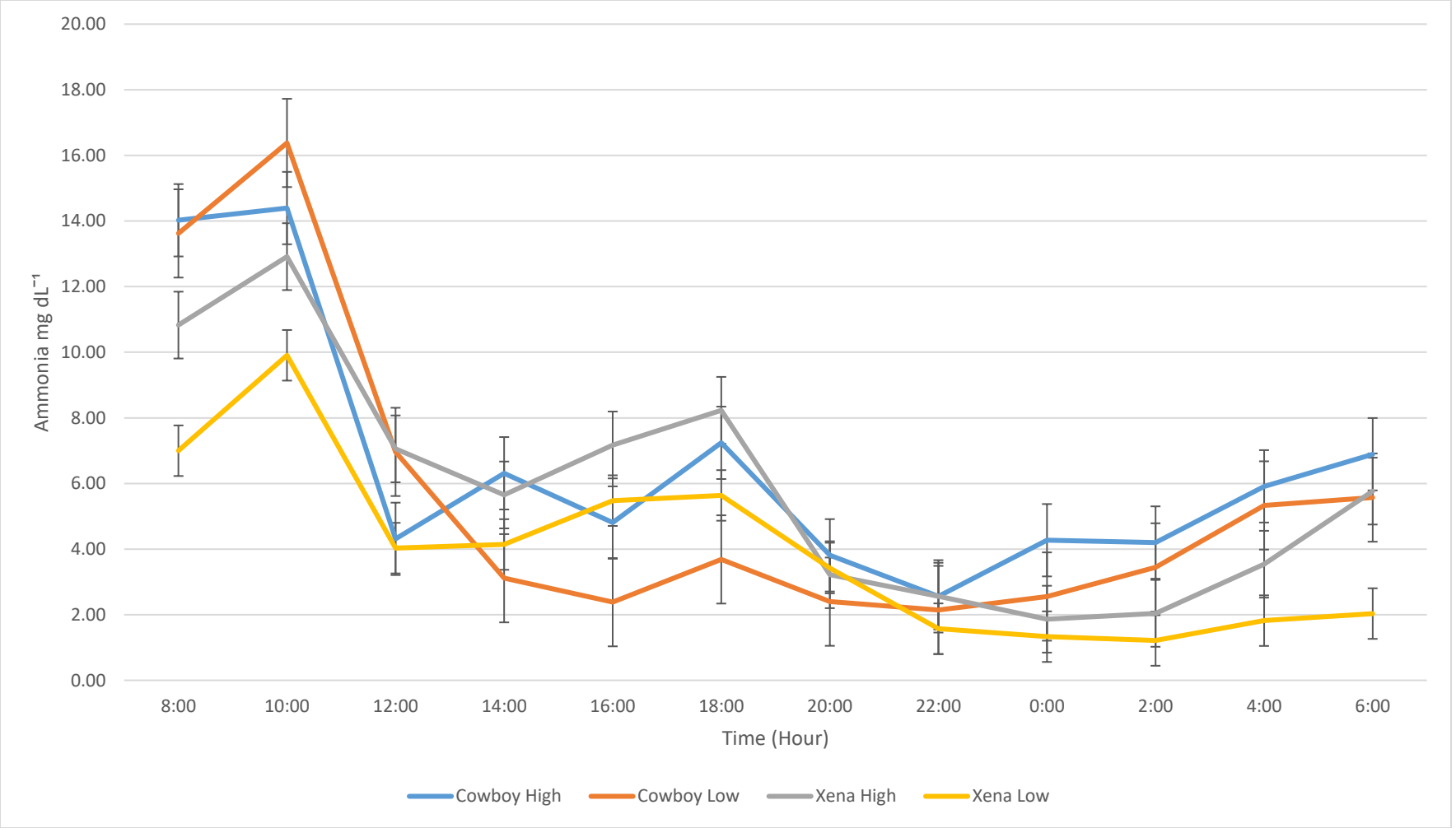

Figure 6. Effect of variety and level of inclusion of barley varieties in finishing diets of feedlot heifers on ruminal ammonia concentration (mg dL^{-1}) averaged over a 24 h feeding period.